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14. ABSTRACT

This Test Operations Procedure (TOP) consolidates and updates information of the world's humid-tropic regions in which US Forces must operate in. The intent of the tropic regions test considerations TOP is to provide the basis and general guidelines for generating specific TOPs for tropic testing of specific categories of materiel.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 01-1-020 — 8 February 2013
DTIC AD No.

TROPICAL REGIONS ENVIRONMENTAL CONSIDERATIONS

1. GENERAL.

1.1 Introduction.

a. The conditions US forces potentially will operate in worldwide must be considered in the research, development, test, and evaluation (RDTE) of materiel. This Test Operations Procedure (TOP) is intended to supplement the requirements contained in Army Regulation (AR) 70-38[1**], for design and conduct of development testing representative of conditions found in the world's humid-tropic regions. This TOP provides a summary of information based upon Bailey's ecoregion classification[2]. By no means was this TOP developed to be a replacement for AR 70-38. Due to the different approaches used to identify zonal regions, no direct correlation can be made between Bailey's ecoregions and the atmospheric conditions contained within AR 70-38. Similar reference TOPs provide equivalent information on the world's dry regions, and cold regions (TOP 01-1-006[3], and TOP 01-1-017[4]). These environmental considerations TOPs provide the background for generation of updated TOPs for environmental testing of specific categories or types of materiel.

b. This document consolidates and updates information of the world's humid-tropic regions in which United States (US) Forces must operate in. The intent of the tropic regions test considerations TOP is to provide the basis and general guidelines for generating specific TOPs for tropic testing of specific categories of materiel.

c. The environmental consideration TOPs introduce a methodology for characterizing potential operating environments worldwide using a standardized method of identification. This method enables the materiel acquisition community to correlate testing at continental US (CONUS) and available outside CONUS (OCONUS) sites with areas of the world that the US cannot access for conduct of RDTE.

d. In this standardized methodology, the world can be described by four primary climatic regions[2,5]: dry, polar, humid-tropical, and humid-temperate, as shown in Figure 1. For the purposes of defining conditions for test and evaluation of Army materiel, the following are definitions used in this document:

(1) Humid tropic regions are the areas within approximately 23.5 degrees north and south of the equator that have a positive moisture balance. The tropics contain mountain ranges where cold conditions occur on at least a seasonal basis. For testing purposes, the primary areas of concern are conditions found in jungles, savannahs, and coastal regions of the tropics.

(2) Humid-temperate regions are the earth's mid-latitude regions (approximately 23.5 ° to 60 ° north and south latitude) with positive moisture balance. These areas have seasonal, but not extreme, temperature variations.

**Superscript numbers correspond to Appendix C, References.

(3) Dry regions are areas where, at least on a seasonal basis, regardless of latitude, losses of water through evaporation exceed annual water gains from precipitation. This results in occasional periods of high potential of dust generation during military operations. The deserts are areas within the dry category where evaporation routinely exceeds precipitation year round resulting in limited ground cover of drought resistant vegetation. Hot-dry areas are deserts where daily temperatures routinely exceed 43 °Celsius (C) (109.4 °Fahrenheit (F)) on at least a seasonal basis. Cumulatively, dry regions occupy the largest portion of the earth's land area.

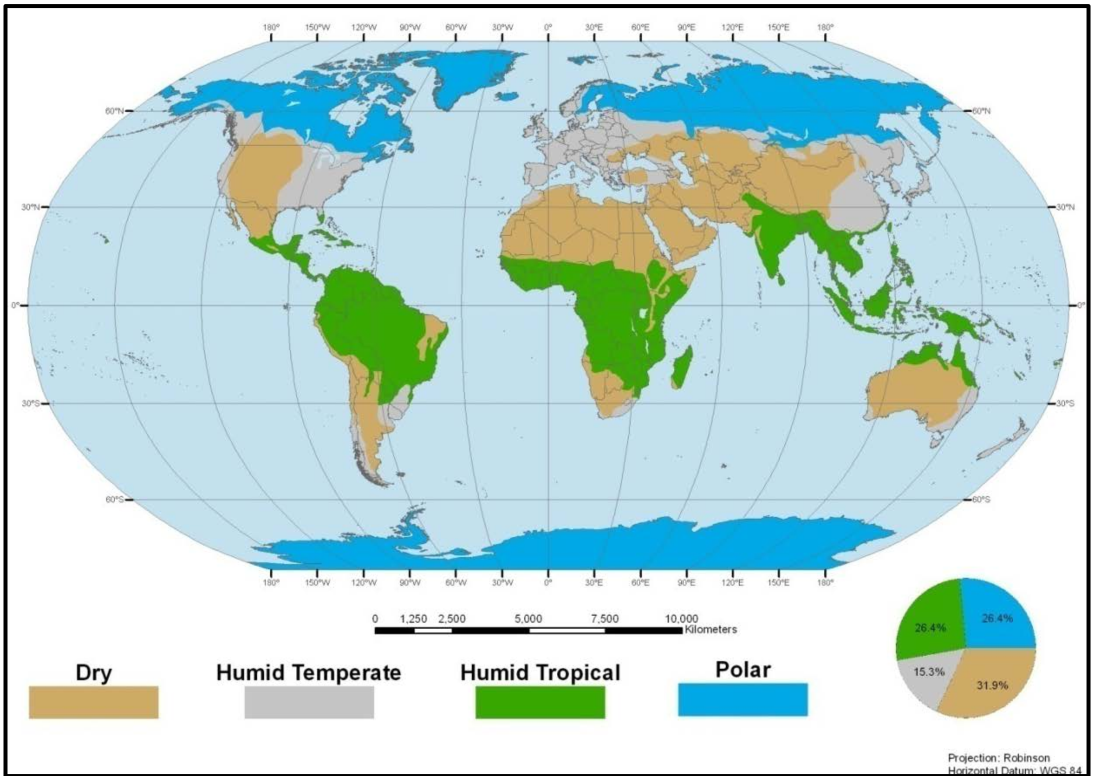

Figure 1. World climatic regions.

(4) Polar (cold) regions are areas, regardless of latitude, where temperatures are below -32 °C (-25.6 °F) for extended periods on at least a seasonal basis. Equipment, especially individual soldier equipment, that will be used in areas such as high mountains where daily or nighttime temperatures are below freezing (0 °C (32 °F)), creating the hazard of frostbite, must be tested for those conditions.

e. The US Army Test and Evaluation Command (ATEC) has established test center locations representing all four of the world's primary climatic regions; humid-temperate region at the Aberdeen Test Center, US Army Aberdeen Proving Ground, Maryland; dry region at Yuma Test Center, US Army Yuma Proving Ground, Arizona; polar region at Cold Regions Test Center, Ft. Greely, Alaska; and humid-tropic at tropic test sites in accessible OCONUS locations.

f. These regions can be further subdivided into categories that naturally occur based on environmental factors such as terrain, vegetation, and seasonal variability to more fully describe the actual conditions US military forces will experience during worldwide operations. Once these factors are added, along with induced factors such as dust that result from military operations, a new descriptive term evolves-Military Operating Environments (MOEs).

g. The test and evaluation community must consider factors such as the overall temperature extremes found in the climatic regions along with the environmental factors characterized as the MOE in the determination of criteria for materiel testing.

h. The relative impact of environmental factors are then prioritized based on performance of basic military functions-ability to move, shoot, and communicate-plus impact on the Soldiers' welfare and comfort. The environmental considerations TOPs will provide the methodology to do this.

1.2 Scope.

The primary intended use for this TOP is to specify the conditions in the tropics, and provide descriptions of sites available for communications, sensors, chem-bio, as well as vehicle and Soldier systems tests.

1.3 Purpose.

This is an overview TOP and is organized to provide background information on the humid tropical region environment and the effect of tropical weather on human physiology and military materiel. This information should be used in preparing for and understanding the need for testing in a humid tropical environment. The tropical environment can physically alter the size of materiel by causing swelling and changes in weight that can be detrimental to packaging, permeability, and tensile strength of military equipment. The increased surface deterioration, fungal growth, and corrosion can alter the expected functional lifespan of equipment by increasing the cleaning cycles and causing items to fail sooner than expected.

1.4 Humid Tropical Environment.

a. The humid tropical environment is a complex and variable ecosystem. The tropical regions are considered to be a broad belt of the Earth's surface bordering the equator, between 23.5 ° north latitude (Tropic of Cancer) and 23.5 ° south latitude (Tropic of Capricorn) as determined by Appendix A of the Unified Facilities Criteria (UFC) 3-44005N[6]. The two most distinctive and widely recognized elements of tropic regions are the constant warm temperatures and constant high humidity. However, the specific boundaries of areas considered to be tropical in nature depends on the interplay of ocean currents and atmospheric circulation patterns with the major continental land masses. The tropics include approximately 15 percent of the Earth's land surface and 53 percent of countries and territories worldwide contain areas of tropics. The climate of the tropics is dominated by equatorial and tropical air masses and characterized by warm temperatures and high rainfall. Climate classification systems[7] that combine the characteristics of temperature and precipitation define the tropics as regions in which average monthly temperatures are in excess of 18 °C (64.4 °F), where there is no winter season, and in which annual rainfall is large and exceeds annual evaporation. Not addressed in this TOP are storm surges, earthquakes, tsunamis, or active volcanoes.

b. The two MOEs of the tropic region are Savanna and Rainforest (see Figure 2, and references 4 and 5). Both the Savanna and Rainforest include the dominant atmospheric effects of high humidity with high, constant temperatures, and heavy precipitation. These conditions exist year-round in the Rainforest MOE and seasonally in the Savanna MOE. Other distinguishing effects in these MOEs are seen in the terrain and biological factors.

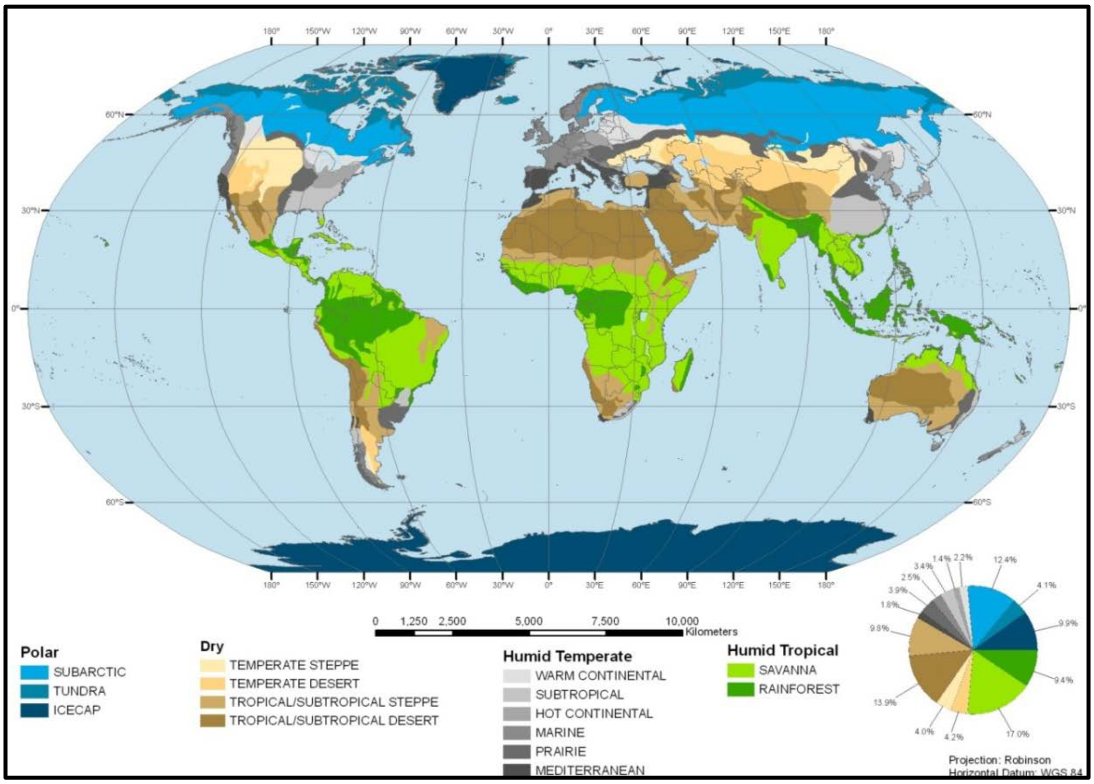

Figure 2. Military Operating Environments.

1.4.1 Savanna Military Operating Environment.

The Savanna MOE is the transition zone between rainforest and more arid locations. Large areas of Savanna surround rainforest locations in Brazil and central Africa, and exist in India and northern Australia. Mean temperatures during all months exceed 18 °C (64.4 °F). The Savanna is characterized by distinct wet summer (heavy rainfall) and dry winter (both more than two months in length) seasons. Dominant vegetation includes tall grasslands that contain drought-tolerant shrubs and trees, though dense tropical forests can occur along streams. Rivers and streams experience high seasonal fluctuations. Plains and plateaus are common surface features. Soils are characterized by heavy leaching. Savanna includes low-interior plains and plateaus.

1.4.2 <u>Rainforest Military Operating Environment</u>.

The Rainforest MOE exists in equatorial locations from 10 ° north to 10 ° south latitude, including the central African Congo, South American Amazon, parts of southeastern Asia, and the Indonesian Islands. The rainforest has a wet equatorial climate, no distinct dry season, and all months exceed 60 millimeters (mm) of rainfall. Mean monthly temperatures during all months exceed 18 °C (64.4 °F). Soils are rich in hydroxides of iron, magnesium, and aluminum. The stream flow is constant throughout the year. Rainforest includes major river basins and plateaus with low interior plains, high-interior plains, and coastal plains.

1.4.3 <u>The Environment In The Humid Tropical Region</u>.

a. Atmospheric Factors.

(1) Ambient Temperature.

(a) Temperature in humid tropics is generally not prone to extremes. Temperatures greater than 38 °C (100.4 °F) are rare events. Likewise, temperatures below freezing (0 °C (32 °F)) are uncommon. The average low for this region is 20 °C (68 °F) and the average high is 30 °C (86 °F), with an annual mean temperature of 26 °C (78.8 °F). Also, there is little variation in diurnal temperature due to the insulating effect of clouds and moisture. Generally, the temperature can be expected to be between 20 °C (68 °F) and 30 °C (86 °F), regardless of season or time of day. Figure 3[1] presents daily cycle of ambient temperature in open tropic areas.

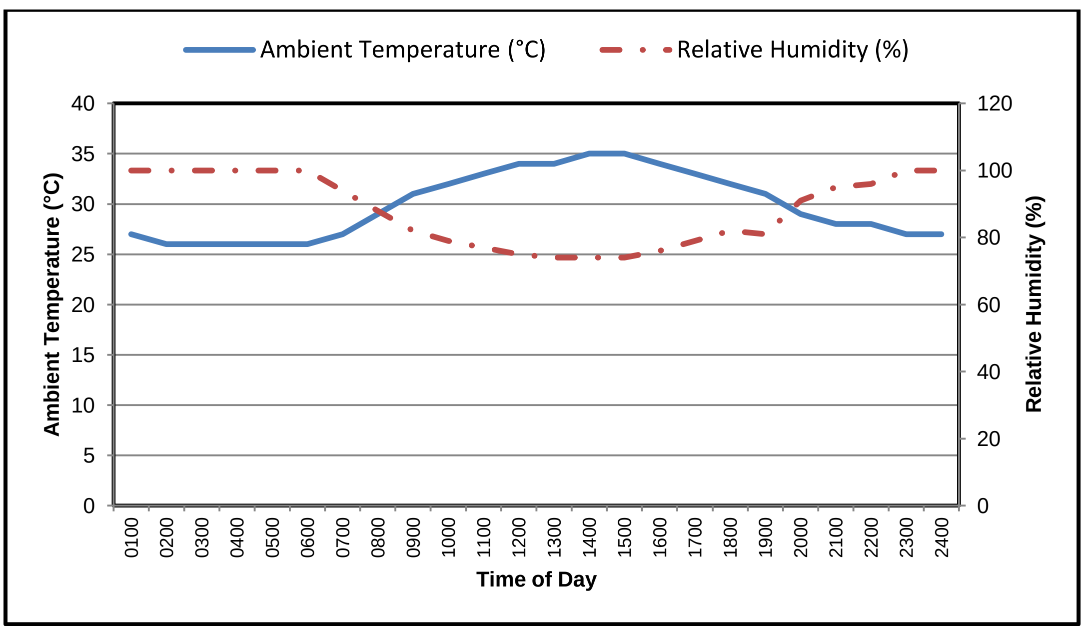

Figure 3. Basic climatic design type variable humidity daily cycle of ambient temperature and relative humidity

(b) It should be noted that mountainous regions are an exception. Temperature decreases as altitude increases regardless of latitude. Some of the highest peaks in the humid tropical region have temperature regimes that are or approach polar conditions. Figure 4[8] shows the global distribution of maximum temperature; Figure 5[8] shows the global distribution of minimum temperature.

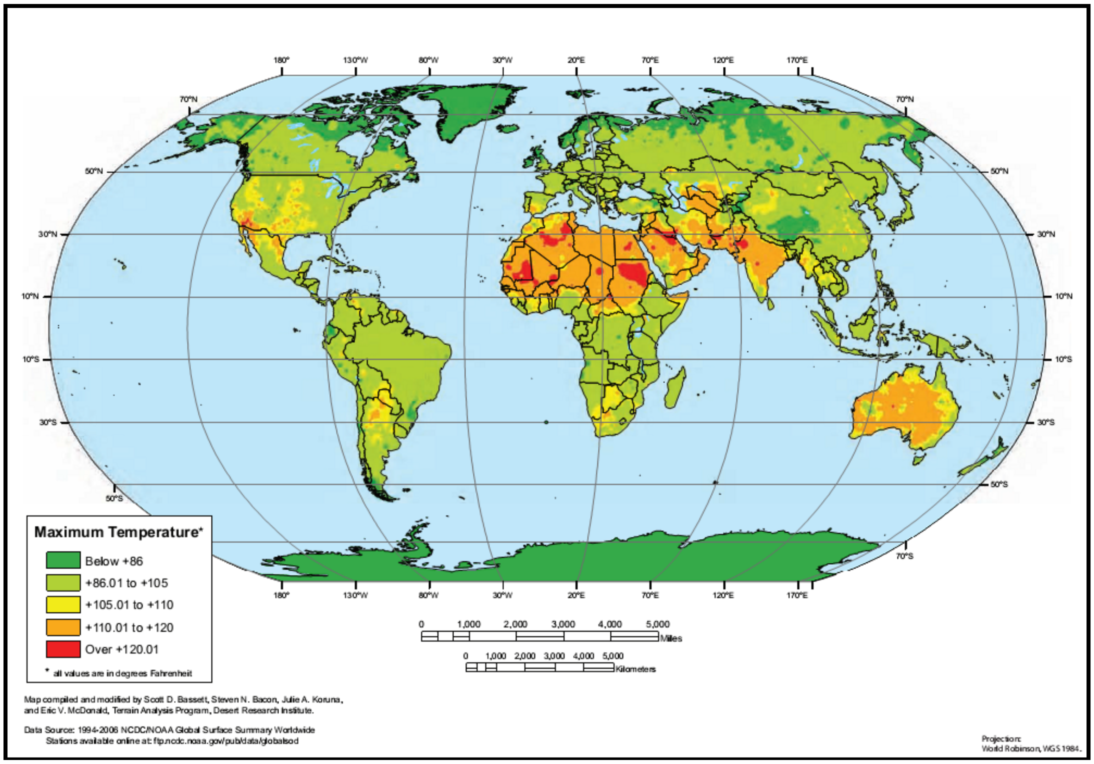

Figure 4. Global maximum temperature map.

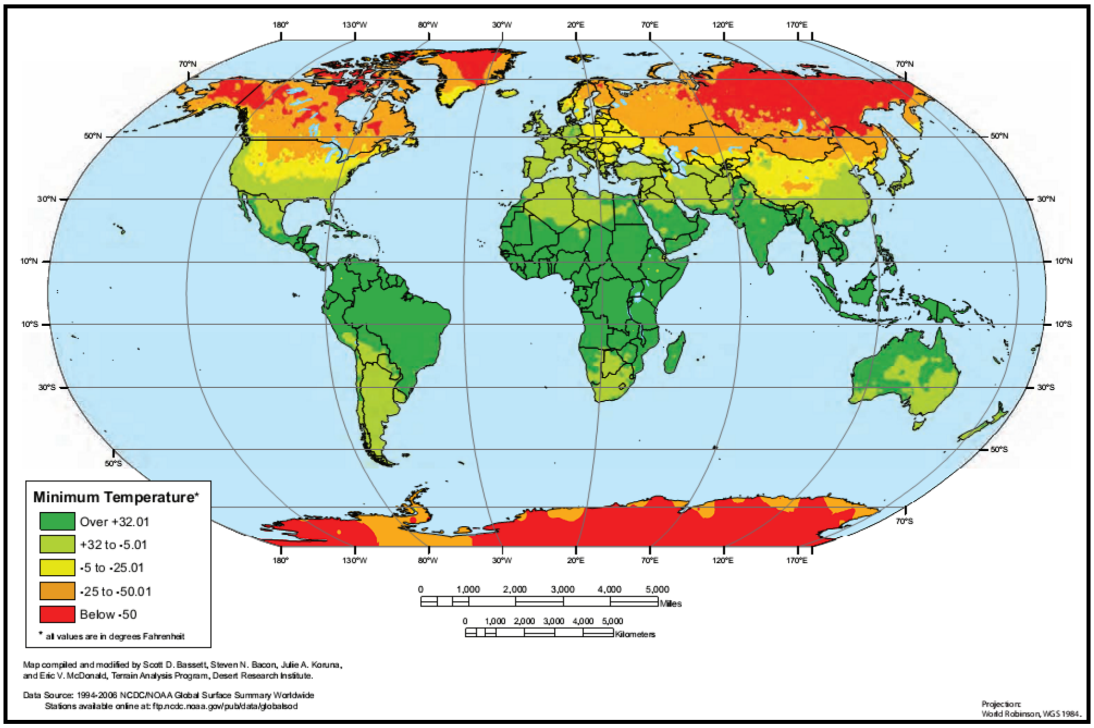

Figure 5. Global minimum temperature map.

(2) Relative Humidity (RH).

Constant RH is a defining characteristic of the humid tropics. Daily RH typically varies from 88 percent to near saturation (100 percent) in heavily forested areas, and from 74 percent to near saturation in open areas per Military Handbook (MIL-HDBK)-310[9]. Relative humidity in the range of 70 percent to 100 percent for most of the year is normal in the Rainforest MOE and some microclimates, such as cloud forest, but may remain near saturation year round. The drier Savanna MOE will experience similar conditions for at least part of the year, but may also experience drought conditions with substantially lower RH on a seasonal basis (see Figure 6). Figure 3 presents daily cycle of relative humidity in open tropic areas.

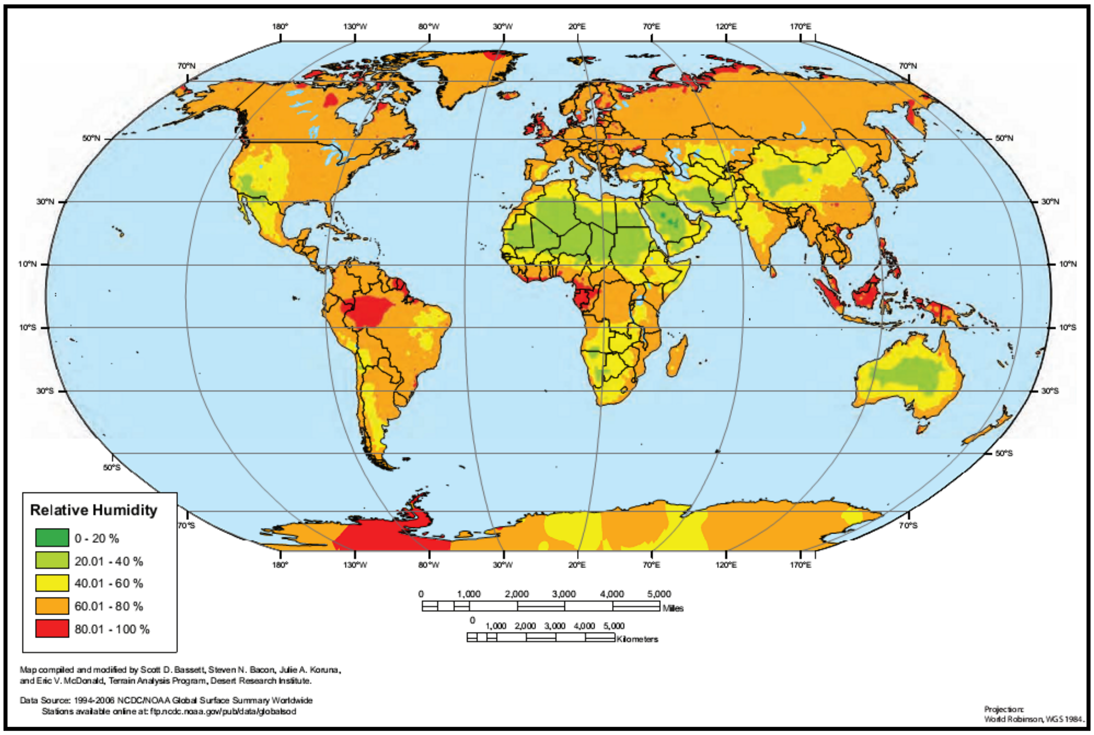

Figure 6. Global distribution of average relative humidity.

(3) Precipitation - Rain.

(a) Precipitation varies in the tropics, from 500 mm annually in the Savanna, to over 2000 mm in the Rainforest MOE. The Savanna MOE has a dry season ranging from 5 to 8 months in duration, and a wet season lasting from 2 to 8 months. During the dry season monthly rainfall may be as low as 8-10 mm but can increase to over 200 mm during the wet season. The Rainforest MOE may also have a dry season, or may have relatively constant rainfall throughout the year. If there is a dry season it is of lesser length than the Savanna, 3 months or less. For the Rainforest, dry season is relative, some areas will have monthly rainfall greater than 200 mm and all receive at least 60 mm each month. Rainfall in the humid tropics ranges from fine, mist-like rain to torrential downpours exceeding 200 mm in a 6 hour period. During prolonged rain periods or intense rainfalls, flood conditions, ponding, and runoff conditions can occur. Vast areas, such as parts of the Amazon basin, flood on a seasonal basis and become passable only by boat (reference 6). Figure 7 (reference 8) presents the global distribution of average annual precipitation and Figure 8[10] presents a comparison of annual precipitation at several environmental test sites.

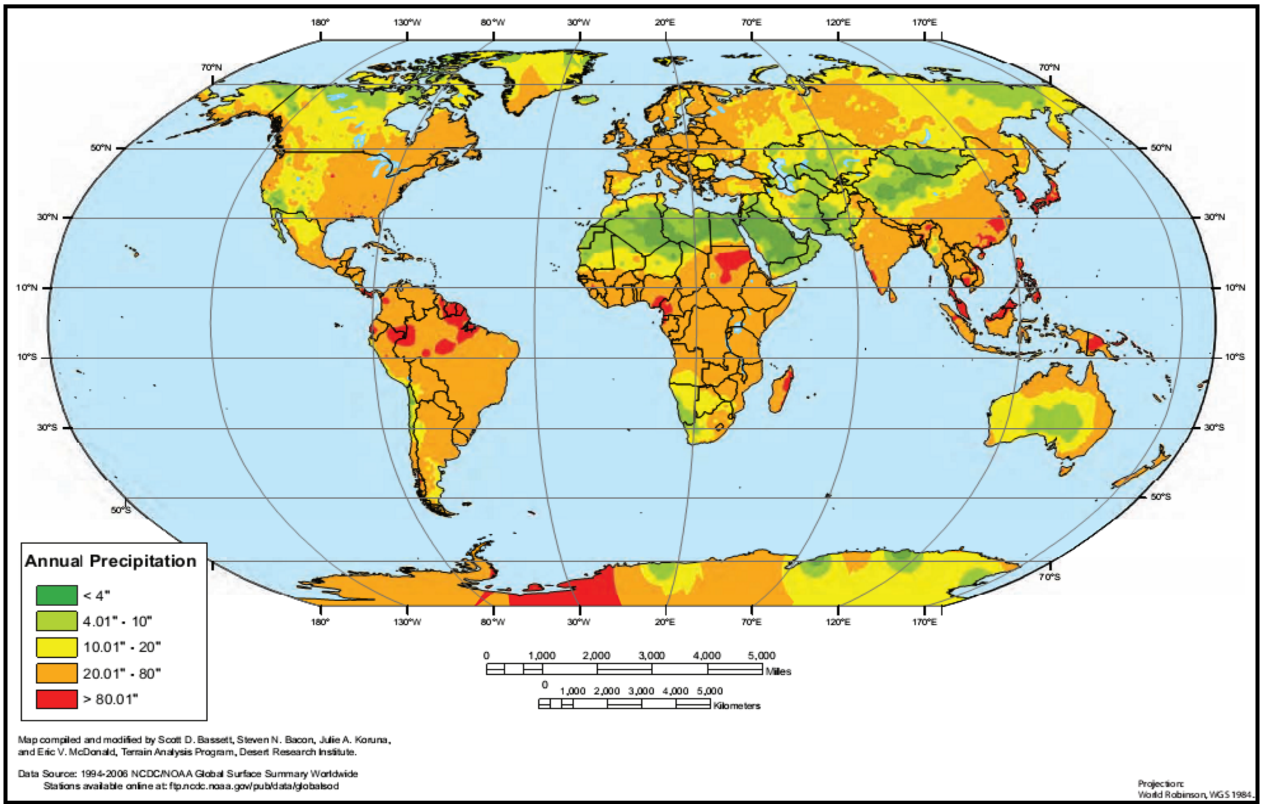

Figure 7. Global average annual precipitation map.

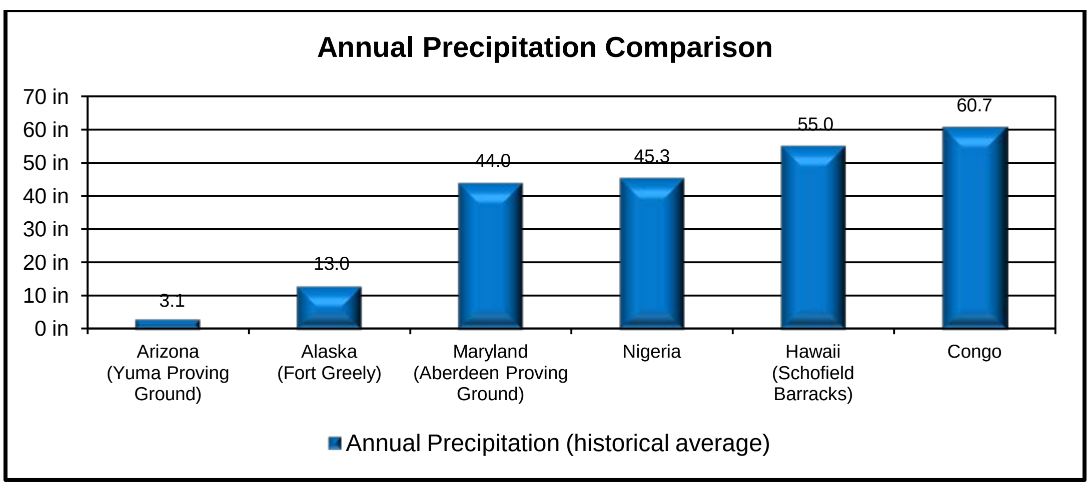

Figure 8. Annual precipitation comparison.

(b) As an example, rainfall is extremely variable in the Republic of Panama both in location and time. On the average, the Atlantic side of the Republic of Panama has an annual rainfall of approximately 3302 mm. The wettest month is November averaging 560 to 610 mm, and the driest months are February and March averaging 25 to 50 mm. On the Pacific side of the

Republic of Panama, annual rainfall averages 2030 mm. The wettest months are October and November averaging 280 mm each, and driest months are February and March averaging less than 25 mm per month. Figures 9, 10, and 11 present monthly rainfall maximum, average and minimum for Pacific, Mid-Isthmus, and Atlantic sites respectively. Table 1 presents rainfall yearly totals for Pacific, Mid-Isthmus, and Atlantic sites based on US Army Tropic Regions Test Center (TRTC) historical data. The maximum average rainfall generally occurs one - half month earlier on the Pacific side.

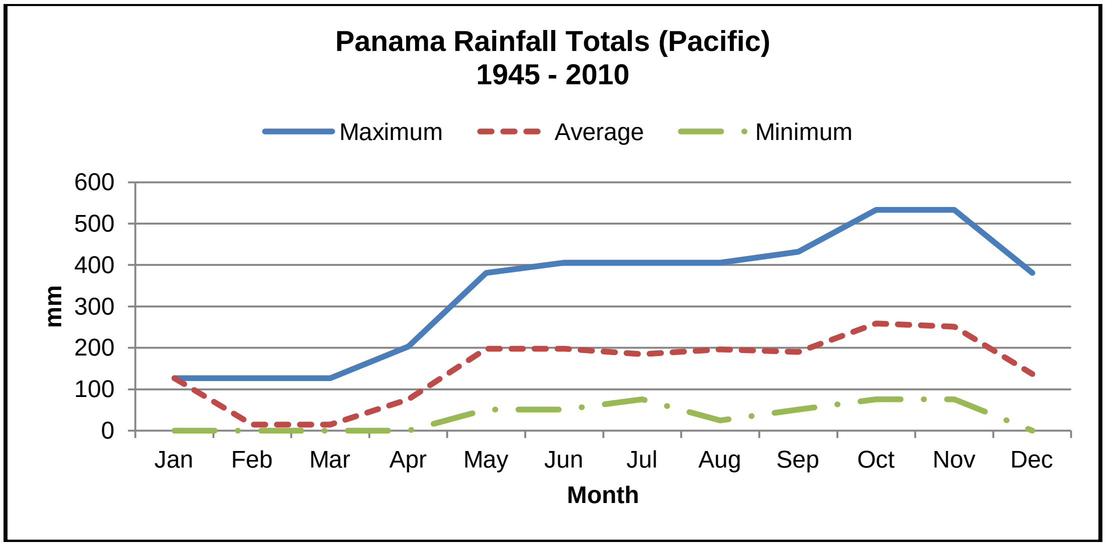

Figure 9. Panama rainfall totals (Pacific).

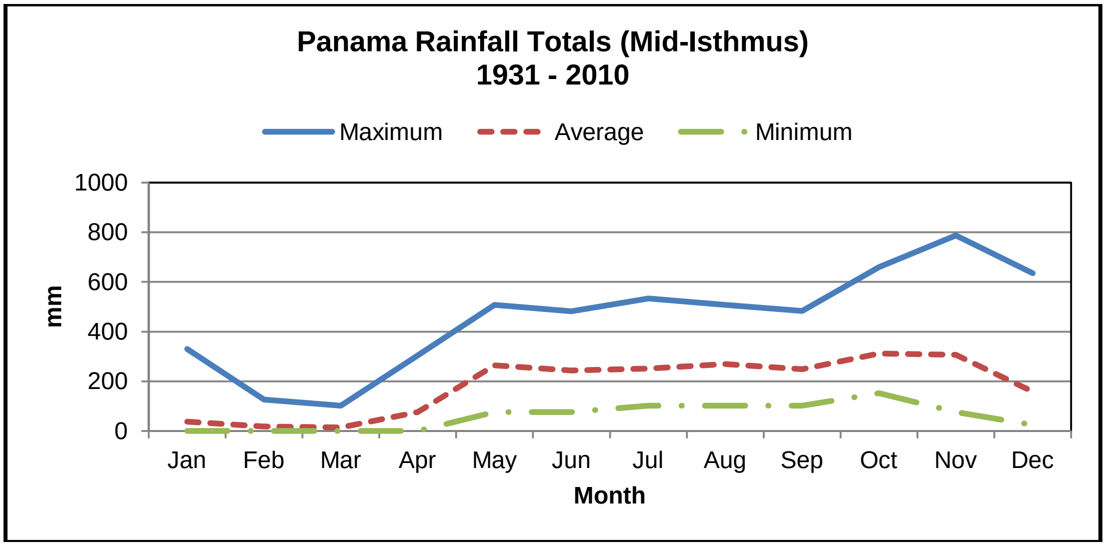

Figure 10. Panama rainfall totals (Mid-Isthmus).

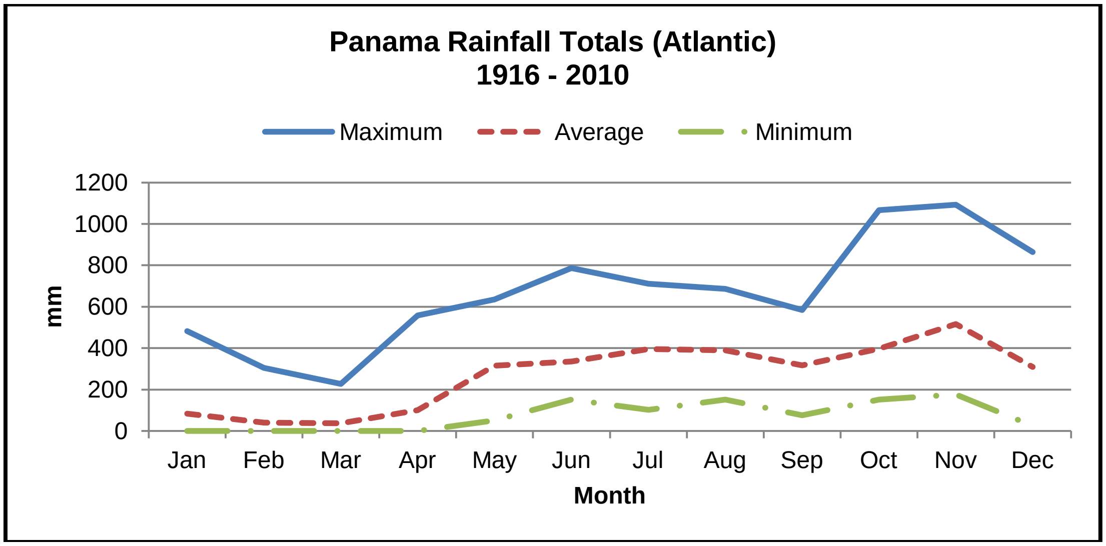

Figure 11. Panama rainfall totals (Atlantic).

TABLE 1. PANAMA RAINFALL YEARLY TOTALS

LOCATION	MAXIMUM, mm	AVERAGE, mm	MINIMUM, mm
Pacific (1945 - 2010)	2362	1751	1244
Mid-Isthmus (1931 - 2010)	3454	2205	1575
Atlantic (1916 - 2010)	4648	3277	2184

(c) The greater rainfall on the Atlantic coast is explained by tropic wind patterns. In almost all tropic zones, easterly winds prevail with a tendency to northeast on the northern hemisphere and southeast on the southern hemisphere. Hence, Panama has onshore winds at the Atlantic coast, and winds from land to ocean at the Pacific coast most of the time. Wind moving against a coast is forced upward because of convergence caused by increase of friction. The air mass when moving upward becomes cooler because of the decrease in atmospheric pressure in the upper atmosphere. Clouds form when the dew point is reached; and, when the supply of fresh water condensate is greater than the air can hold, it rains. Additional factors result in a tendency toward intense, local showers rather than moderate, wide- spread rain. Rainfall decreases as the air moves across the isthmus, losing its moisture[11].

(4) Wind.

(a) Wind is a complex atmospheric phenomenon that occurs at multiple scales, from local air movement lasting minutes to persistent global winds. When considering surface winds, the area having the highest wind gusts in the world (excluding mountain peaks and tornado tracks) is the typhoon belt of the western North Pacific Ocean, an area of the humid tropics which otherwise has relatively low wind speeds. Generally, average wind speed in the humid tropics is less than 1.4 meters per second (m/s) and seldom exceeds 3.6 m/s.

(b) Figure 12 presents the global distribution of average surface wind speed, Figure 13 presents the global distribution of maximum surface wind gusts, and Figure 14 presents the global distribution of maximum sustained wind speed. The data in Figures 12 through 14 were derived from reference 8. Figures 15 and 16 present wind speeds at 2 meters (m) above ground level (AGL) for Pacific, and Atlantic sites in the Republic of Panama. The data in Figures 15 and 16 were derived from Empresa de Transmision Electrica S.A. (ETESA) historical wind data, compiled in 2012).

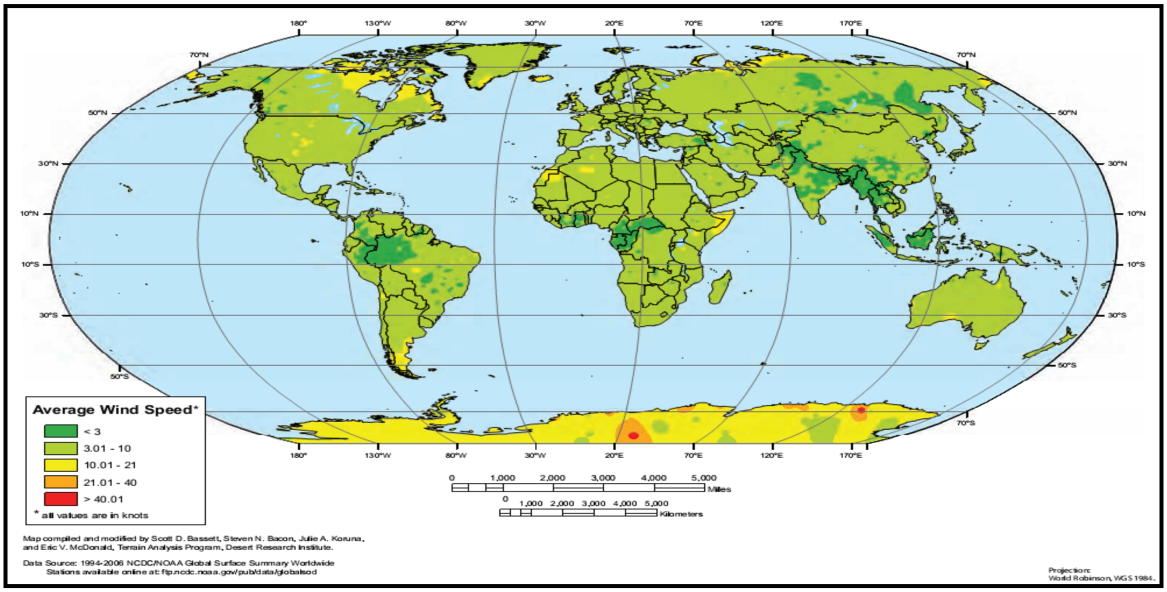

Figure 12. Global average wind speed map.

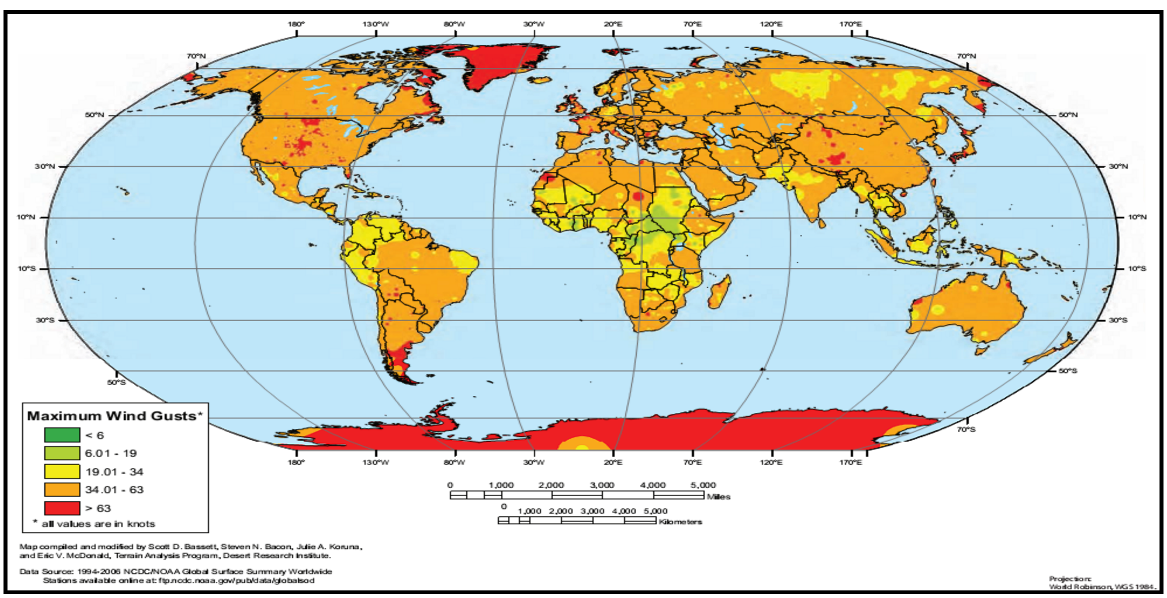

Figure 13. Global maximum wind gust map.

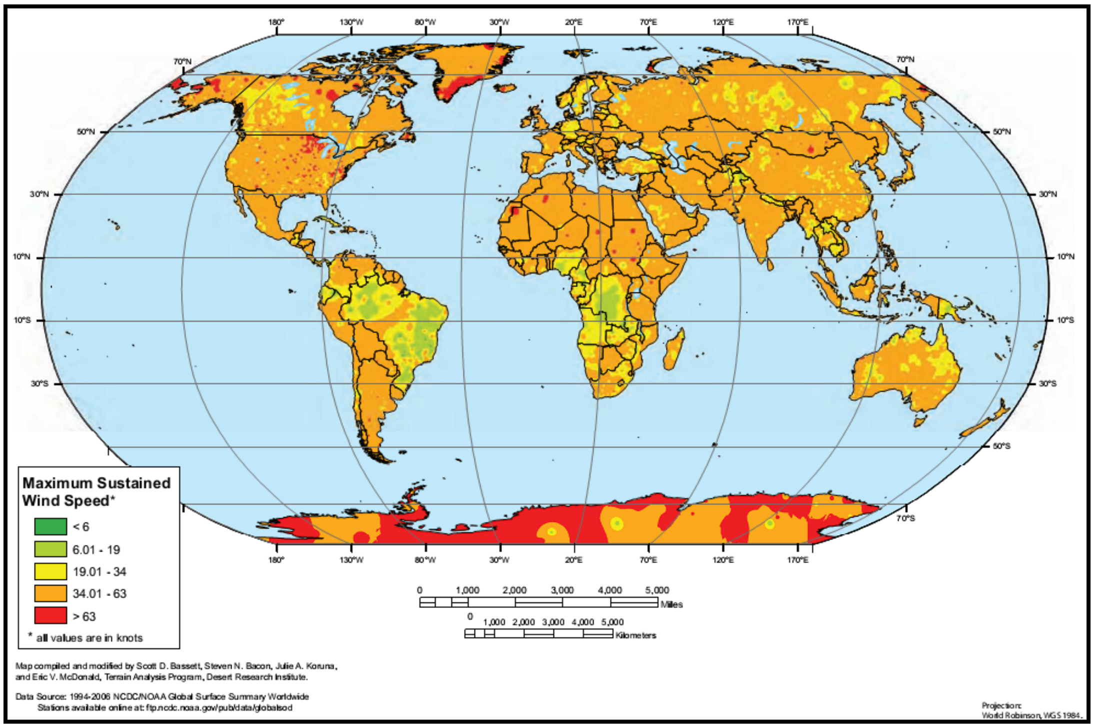

Figure 14. Global maximum sustained wind speed map.

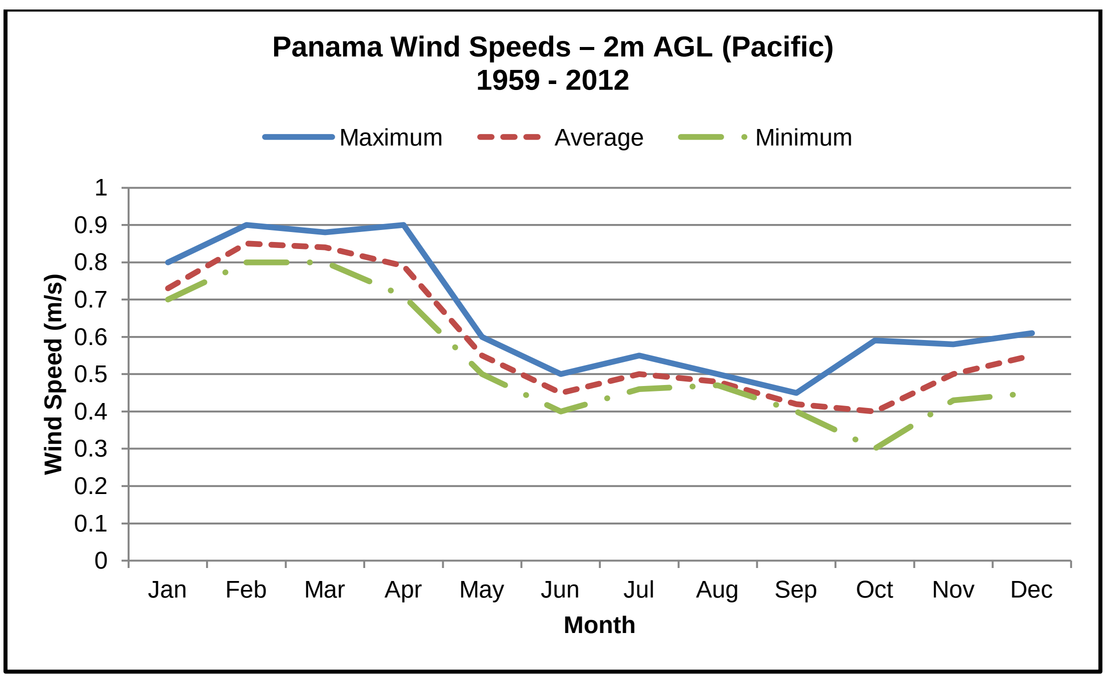

Figure 15. Panama wind speeds - 2 m AGL (Pacific).

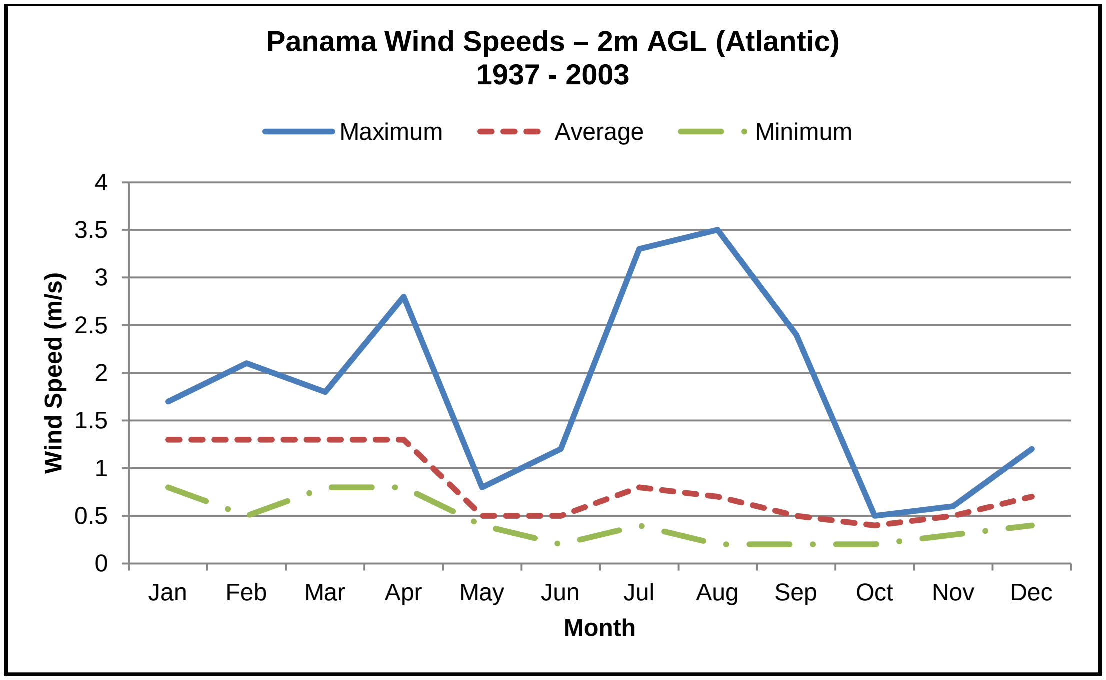

Figure 16. Panama wind speeds - 2 m AGL (Atlantic).

(5) Typhoons.

(a) The terms “hurricane” and “typhoon” are regionally specific names for a strong “tropical cyclone”. Tropical cyclones with maximum sustained surface winds of less than 17 m/s (33.0 knots) are called “tropical depressions”. Once the tropical cyclone reaches winds of at least 17 m/s (33 knots) they are typically called a “tropical storm” and assigned a name. If winds reach 33 m/s (64.1 knots) then they are called a “hurricane”, “typhoon”, “severe tropical cyclone”, “severe cyclonic storm”, or “tropical cyclone”[12].

(b) Tropical storms, typhoons, and hurricanes frequently cause storm surges. Storm surge is simply water that is pushed towards the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the hurricane storm tide, which can increase the mean water level 4.6 meters (15.1 feet) or more. In addition, wind driven waves are superimposed on the storm tide. This rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with the normal high tides[13].

(6) Solar Radiation.

When not attenuated by forest canopy or cloud cover, humid tropics receive the most direct, and therefore, most intense solar radiation. Before atmospheric attenuation, this region receives over 34.6 mega joule per square meter per day (MJ/m^2/day) of solar radiation; however, due largely to the presence of water vapor, it receives approximately 17.3 MJ/m^2/day at the surface. Although ambient temperature is usually around 27 °C (80.6 °F) in the tropic regions, surface temperature of an object exposed to direct sunlight may reach 82 °C (179.6 °F) or greater, depending on the material (reference 6). Figure 17 presents average solar radiation values for Pacific, Mid-Isthmus, and Atlantic sites in the Republic of Panama (reference 11).

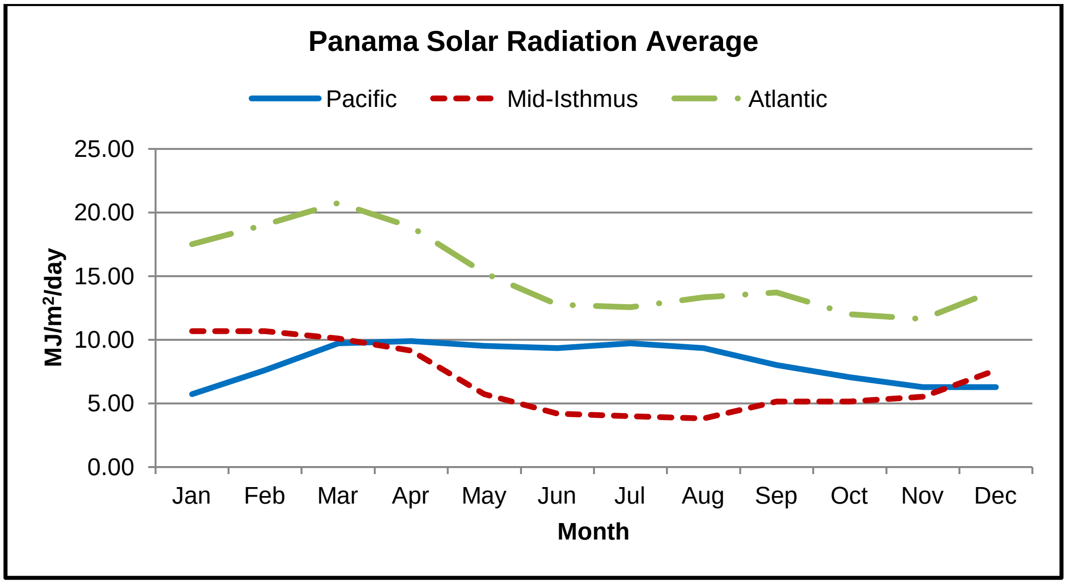

Figure 17. Panama solar radiation.

(7) Induced Climatic Conditions.

(a) The environment experienced by items exposed in tropic locations is often much different from that measured using standard meteorological techniques.

(b) During the Storage and Surface Temperatures in the Humid Tropics[14] effort conducted by TRTC, storage and surface temperature of five structures in the humid tropics of the Republic of Panama were measured. They included: a large ventilated warehouse, an ammunition bunker, an unventilated sheet metal building, a general purpose tent, and a transportation container (CONEX). Mean maximum temperatures measured at various points in the structures ranged between 26 °C (78.8 °F) in ammunition bunker and 62 °C (143.6 °F) in fabric outside of general purpose tent. Solar induced temperatures inside the storage structures showed much higher variability than outdoor ambient temperatures except for the ventilated warehouse and the ammunition bunker. Although higher ambient temperatures were recorded during the dry season, the maximum storage temperature occurred during the wet season when the atmosphere was clear and wind speeds were low.

(c) The Moisture and Temperature Conditions in Storage Containers in Humid Environments [15] effort conducted by TRTC, documented extreme surface temperatures and temperature fluctuations for structures in open exposure during the wet season. The maximum temperature measured was 89 °C (192.2 °F) in the air space between the metal roof and the insulation layer of a military-owned demountable container (MILVAN). All extreme temperature fluctuations occurred between 1100 and 1400 hours and were caused by rapid changes in cloud cover or by contact with sudden rain showers.

b. Terrain Factors.

(1) General Physiography.

Tropical regions can be broadly divided into three end-member physiographies: high-relief ocean islands and coastal regions typically in a neo-volcanic setting, flat atoll-type islands or low-gradient river basins, flood plains and deltas, and elevated savanna. In general, the high-relief tropics are characterized by sandy beaches, a coastal plain of variable width, and a rugged interior topography. The low-relief tropical river basins typically meander across wide areas, with thick vegetation upstream and backwater and coastal swamps near the coast. Upland regions of tropical savanna are grasslands developed upon rolling hills and plateau that are deeply cut by channels and gorges[16].

(2) Soil Conditions.

Soil profiles are well developed in the wet tropics, with strongly-leached lateritic soils (red-yellow residual oxidized soil) characteristic of this climate. Often referred to as oxisols these soils consist of a mixture principally of clays, hydrates, oxides, and quartz (see reference 5). On atoll type islands the soils are coral or coralline Limestone. In both MOEs these soils are usually covered by a thin layer of organic soil between 51 and 305 mm thick, consisting of leaf litter and other biological detritus. Should this layer be disturbed, the resulting clay derived mud can be very slippery.

c. Bioilogical Factors.

(1) The major biological considerations for a tropical testing site are the vegetation characteristics and presence of a diverse community of above- and below-ground organisms. In the past, military interest in tropical vegetation was primarily its structure and distribution in both horizontal and vertical dimensions as challenges to vision, mobility, and performance of personnel and equipment. For other organisms, especially microbes and fungi, the concerns focus primarily on the metabolic processes that foul materiel and interfere with equipment and systems under test. Military testing at present and in the future requires much greater detail and understanding of the structure, function, and interrelationships of species in complex tropical ecosystems (see reference 16).

(2) The terrestrial world is subdivided into eight biogeographic realms and fourteen biomes[17], as shown in Figure 18. Tropics are predominant in the Neotropics, Afrotropics, Indo-Malay, and the Oceania realms. Of the 867 ecoregions nested within these realms and biomes, 463 are in the tropics.

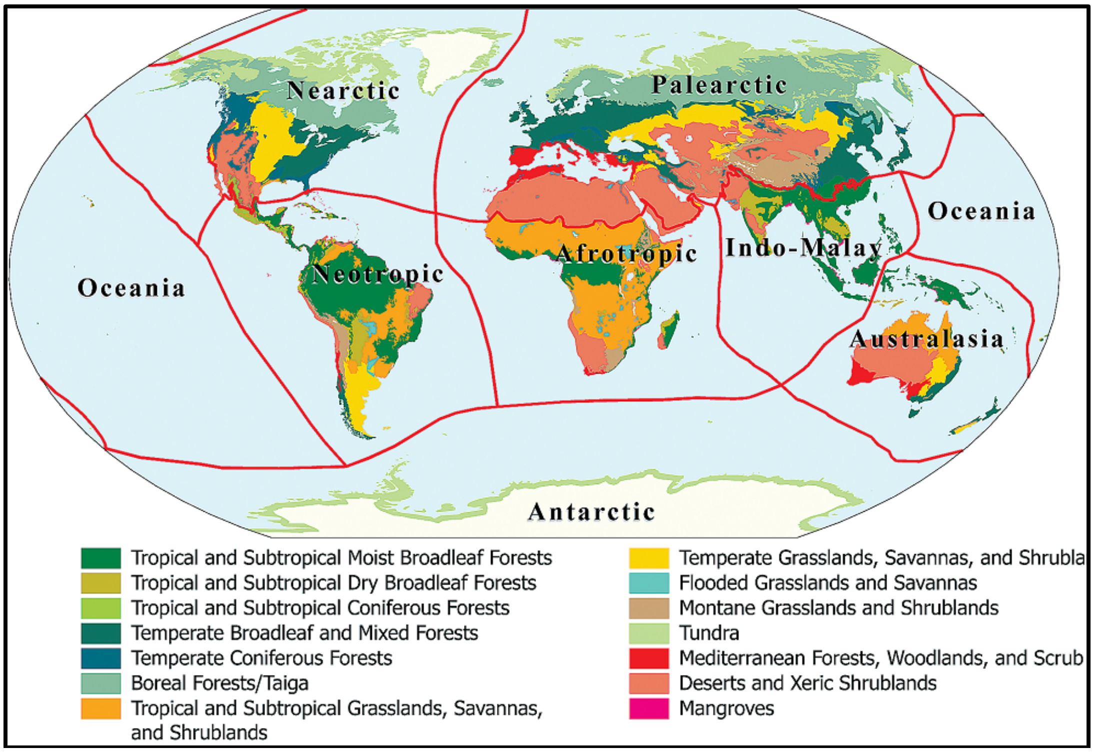

Figure 18. Terrestrial ecoregions map.

(a) Vegetation. Vegetation in test areas is classified in accordance with the Holdridge Life Zone Classification System[18]. This system is based on the theory that vegetation structure (type) is directly dependent on temperature and precipitation, with some modifications (termed associations) caused by other factors. The system works well for describing tropic vegetation.

1 Savanna Vegetation. The type of vegetation found in the savanna varies depending largely on the intensity and duration of the dry season. Areas that receive ample precipitation throughout the year are typically dry tropical forest and woodland, including drier types of Miombo and Sudanian woodland, savanna (Africa), caatinga and Chaco (South America), and dry deciduous dipterocarpus forest and woodlands (Asia). Dense tropical forests occur along streams and rivers. The more arid portions of the savanna tend to be characterized by extensive grasslands, interspersed with areas of shrubs and short trees. These grasslands can have very tall, thick grasses up to 5 meters high and the drought tolerant shrubs and trees often possess thorns. Mangrove swamps, palm swamps, and dense tall grasses may be present in low lying swamps and coastal areas in savanna or rainforest.

2 Rainforest Vegetation. With no significant dry season, tropical evergreen and semi-evergreen rainforest dominates. The vegetation is lush, with tall, closely set trees that often form a continuous multi-layer canopy and emergent trees reaching a height of 50 to 60 meters. The lowest level may be densely packed with vegetation, or, if the upper canopies are dense enough to block the sun, may be almost barren. Some plant species in this environment

are dangerous to come in contact with. Such plants, that are native to Central and South America, include cowhage, lantana, the manchineel tree, the rengas tree, nettles, and the stinging tree. A number of plants in the Rainforest also have spines or thorns, such as the black palm, rattan, and lawyer vine. The tropical rainforest is the most diverse terrestrial ecosystem with a large number of tree species.

3 Mountain Vegetation. Due to variation in climatic conditions with elevation, there are a variety of vegetation types along elevation belts, ranging from evergreen rainforest, cloud forests, conifer forests, to alpine tundra. Sclerophllous forest, shrub land, and grassland are found on the leeward lowlands.

(b) Macro-organisms. The tropical regions are home to the largest diversity of insect and animal life on Earth. Most of these creatures are harmless to humans, human activities, and equipment. Only those organisms that affect people, material, or operations are discussed here.

1 A small area of rainforest may contain several thousand insect species and hundreds of individuals in a square foot. Most of these insects are decomposers or scavengers that consume dead leaves and other organic matter on the forest floor. Predominantly termites and ants, these animals search the ground, crawling in, on, or through everything in contact with the ground in search of anything edible. This would include virtually anything organic like food and most fabrics, but also some inorganic materials like plastics and rubbers. Small vertebrates, primarily rats and mice, exist in abundance in tropic regions. Like insects, these animals search the ground for food. Rodents present the same problems for materiel that rodents everywhere else do, mostly where they nest and their tendency to bite things.

2 Parasites present the greatest threat to human health. Some parasites cause disease or injury directly while others act as a vector carrying disease. Parasites like mosquitoes, fleas, ticks, leeches, and kissing bugs act as vectors for many diseases like Malaria, Yellow Fever, Rift-Valley Fever, Dengue Fever, American Trypanosomiasis (also known as Chagas Disease), several hemorrhagic fevers, dozens of bacterial infections, and various forms of encephalitis. They also create injuries that can become infected. Mosquitoes present the greatest hazard due to their abundance and wide distribution. There are many other parasites, collectively known as helminthes, like flatworms, roundworms, and flukes that cause disease directly. Contaminated food or water is the source for virtually all of these.

3 There are a number of insects whose bite, sting, or even hairs are poisonous. Bees, wasps, centipedes, spiders, scorpions, the rice-borer moth, the bristleworm, and some species of ants have a bite, sting, or are otherwise venomous. Most of these only cause pain and swelling upon envenomation, but a few can threaten life. Envenomation is the process by which venom is injected by the bite (or sting) of a venomous animal. The banana spider of South and Central America, the funnel-web spiders of Australia, and several small scorpion species are known to have caused death. The remainder is not usually lethal unless the victim is allergic to the venom.

4 Larger vertebrate animals often affect people rather than presenting a problem for materiel. Several species of venomous snakes inhabit the humid tropics including

the Bushmaster, the Fer-De-Lance, cobras, pit vipers, and rattlesnakes. Except for large predators like jaguars and crocodiles, large animals are dangerous purely because of their size and disposition. It is, however, generally rare for any animal to attack humans unless that animal is cornered or wounded.

(c) Microorganisms.

Microbes, including molds and fungi, exist throughout the local surroundings in water, soil, and air. Moisture, temperature, and food supply are the critical growth factors for microbes. The humid tropics have an abundance of these conditions and support large microbial populations. Among these are many single celled parasites and other microbes that cause disease in humans. Most of these organisms find their home in water or inside other creatures. However, most microorganisms have no effect on human health and exist in the environment acting as decomposers. These microbes are ubiquitous in the humid tropics and will find their way on and inside anywhere there is sufficient moisture and nutrients. These organisms have the ability to chemically break down nearly any organic chemical and can do so very rapidly, especially wood. Many inorganic substances can also be damaged by the waste products and enzymes produced during normal activity.

2. EFFECTS ON SOLDIER AND MATERIEL.

2.1 Environmental Factors That Cause Degradation.

This section describes the natural environmental factors, present in the humid tropical region, that have an effect on operation, storage, and transport of Army equipment in different MOEs. Army materiel is exposed to numerous environmental factors both natural and induced. The challenges and potential risk that the natural environment presents (reference 1) must be addressed and mitigated throughout the materiel design, test, and evaluation process. Induced environmental factors such as nuclear, chemical, battlefield-induced contaminants, electromagnetic impulse (EMI), and electromagnetic compatibility (EMC) are not covered in this document.

2.1.1 Atmospheric Factors.

a. Temperature.

(1) High Temperature.

Although extreme high temperatures above 43 °C (109.4 °F) are uncommon in the humid tropics, high temperature effects do exist, especially with the addition of solar loading and high humidity. High temperatures can detrimentally affect Soldier performance so that operations require careful monitoring of Soldier physical conditions, especially when wearing layers of protective equipment such as body armor or chemical protective suits. A Soldier will also need protection when handling or operating equipment that is exposed to direct sun. The dark finish on equipment can efficiently absorb direct sunlight, thus causing the temperature of the object to rise significantly above the ambient temperature. Hot temperatures cause differential expansion of dissimilar materials, an increased rate of chemical reactions, lowered lubricant viscosity, instability of electronic circuit and displays, insulation failure, alteration of electrical properties, outgassing, deterioration of desired functional characteristics, softening, melting, sublimation, and other effects. The increased rate of chemical reaction will cause batteries to deteriorate rapidly. Performance of internal-combustion engines can degrade due to overheating of the cooling system when operating in high temperatures, also transmissions, and other drivetrain components can build up high temperatures resulting in lubrication breakdown and part failure.

(2) Low Temperature.

Temperatures below freezing in the humid tropics are rare at lower elevations, but are present at higher altitudes and mountains. Low temperature environments are particularly difficult for Soldiers because of the increased need for protective clothing and shelter, which makes movement and maneuver difficult. Low temperatures may also impair equipment operation, either temporarily or permanently, by changing the physical properties of material. Hardening of material, differential contraction of dissimilar materials, increased viscosity of lubricants, changes in electronic components, stiffening of shock mounts, condensation, and freezing of water are just a few of the potential problems. If low temperatures are to be expected, it may be necessary to plan according to Cold Regions environmental requirements (see reference 4).

b. Precipitation - Rain.

Two important effects on materials are as follows: Thermal shock due to rapid cooling caused by water on hot surfaces and wetting of surfaces, thus initiating corrosion processes. Rainwater normally contains dissolved salts and is saturated with oxygen. This water provides an electrolytic path for corrosion propagation. Rainfall is an agent of moisture infiltration into parts, corrosion, and the attenuation of electromagnetic radiation in the atmosphere, thus affecting the performance of some electro-optical systems (e.g. visible and infrared (IR) sights); exposed electrical circuitry is prone to an electrical shock hazard when exposed to rainy conditions. Rainfall can create muddy and slippery conditions which may affect mobility. It also degrades the performance of personnel and their equipment during exposed activities. Tropical rainfall is usually a heavy downpour of relatively short duration.

c. Humidity (Constant and Cyclic Relative Humidity).

Water helps deteriorate materials by serving as the following: (a) A trap for nutrients for bacteria, fungi and other microorganisms; (b) A transport medium for chemicals; (c) A medium for chemical reaction; and (d) A hydration agent for dry materials causing them to swell. Due to slow evaporation rates exposed material is likely to be constantly wet or damp in the Humid Tropics. In combination with high temperature, this quickly produces corrosion, wood rot, and fabric deterioration. High humidity complicates the effect of the ambient temperatures and temperature-humidity variations can trigger condensation, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity of materiel. Condensation inside and on materiel becomes a problem when the relative humidity approaches 100 percent. Water, as vapor, can diffuse into almost any container through pinholes or cracks and condense there.

Relative humidity in the range of 70 percent to 100 percent for most of the year creates ideal conditions for mold and mildew that promote decay. It also accelerates rusting of various metals and intensifies galvanic action in many metals. Many paints in high humidity conditions do not perform well.

d. Wind.

High winds are rare in the tropics except for excessively strong winds from typhoons and hurricanes. These can be damaging to structures and operations. The wind is also often combined with precipitation and can cause reduced visibility and increased moisture penetration. Surface winds are of most concern to Army land operations. However, high altitude winds affect flight of aircraft, unmanned aerial systems (UAS), surveillance systems, and long-range projectiles. At coastal sites, moisture and salt are also transported by wind.

e. Salt/Salt Fog.

(1) Salt and salt-spray are phenomena that affect coastal regions throughout the world. In these areas, yearly salt-fall from all sources varies from a minimum of 28.02 to more than 336.2 kg/hectare/year (25 to 300 lb/acre/year). Daily salt-fall during maximum periods may be as high as 22.4 kg/hectare/day (20 lb/acre/day). A belt of decreasing salt-fall, varying from a minimum of about 3.36 to a maximum of 28.02 kg/hectare/year (3 to 25 lb/acre/year), extends from the coast to a point 80.5 to 1609.3 km (50 to 1000 miles) inland where salt-fall is reduce to minimum (see also Army Materiel Command Pamphlet (AMCP) 706-116[19]).

(2) The principle effect of salt, salt fog, and salt water on materiel is the acceleration of metallic corrosion resulting in loss of mechanical and structural strength, alteration of electrical properties, and surface deterioration. Salt content in air will affect the rate of electrolytic corrosion of metals. Sites with high atmospheric salt levels exhibit high corrosion rates. High salt levels in conjunction with warm temperatures and abundant moisture result in a highly corrosive environment.

(3) Salt-laden air rapidly accelerates wood deterioration, promotes galvanic action between metals, rusting of ferrous metals (including inadequately protected reinforcing steel), and pitting of many aluminum alloys. Salt-laden air also adversely effects the application of paints, sealants, elastomeric coatings, and asphalt roofing applications (see also reference 6).

(4) The severity of salt-laden environments varies throughout the tropics. The degree of intensity varies with elevation, prevailing on-shore wind, vegetation, and rainfall. In addition, small, flat coral islands with sparse vegetation (such as Kwajalein, Midway, and Diego Garcia) have more potential of severe corrosion than do the larger volcanic islands with moderated vegetation and rainfall (such as Hawaii and Guam) (see also reference 6).

f. Solar Radiation.

(1) The most important single effect of solar radiation is the raising of surface temperatures. Temperatures exceeding 71 °C (159.8 °F) have been measured on ordinary surfaces. Temperatures can greatly exceed this under special circumstances. These extreme temperatures greatly exaggerate the normal temperature effects, especially since they are very non-uniform. Typical effects are aging and embrittlement of materials, differential thermal expansion, softening or melting of material, and even evaporation or sublimation of volatile material with possible deposition on cooler surfaces. Embrittlement is a loss of ductility of a material that makes it break without significant deformation. Personnel performance also degrades.

(2) Other effects of solar radiation are due to the direct effect of radiation on materials. Typical examples are: photochemical degradation of materials including discoloration of optics, optical sensor degradation, bleaching of dyes, crazing of paints, cracking of rubber, deterioration of plastics, personnel skin damage, etc.

2.1.2 Terrain Factors.

a. Terrain elements are important because they can affect troop and supply mobility, sensor operations, and both defensive and offensive operations. Mobility is often the prime factor of success in military operations, and terrain character determines the degree and magnitude of trafficability, off-road mobility, and river crossing problems. The effect of terrain on mobility, as well as other operations, is usually the result of the combined influence of several terrain elements; therefore, it is necessary to plan for each of them (see also AMCP 706-115[20] and the Airland Battlefield Environment (ALBE) Tactical Decision Aid (TDA) Demonstration Program Report[21]).

b. Soil Type. The composition and physical properties of soils and related surface cover features are very important to mobility, sensor performance, and engineering construction considerations. Particle size and depth of a soil are important factors upon which cohesiveness, sound wave transmission, and moisture-holding capacity depend. Mud can adversely affect weapon operations. Mud can present a major challenge for mobility, increase wear and corrosion, and cause discomfort to Soldiers.

(1) Rainforest MOE Soils. These soils are relatively stable, with a low to medium expansion potential. With proper moisture conditioning and compaction, oxisols are adequate subgrades below lightly loaded structures. Andisols and vertisols are suitable for agriculture use but do not have sufficient strength and stability for construction use (reference 6).

(2) Savanna MOE Soils. Soils in this MOE range from well weathered types like those found in the Rainforest MOE through poorly formed desert like soils. The degree of soil formation is based on the amount of rainfall and the length and duration of the dry season. Aridisols (dry soil) and entisols (undeveloped soil) are the most common soils in this MOE. These soils may contain a high quantity of sand and during the dry season sand can become a problem for mobility and cause excessive wear on moving parts.

c. Surface Water.

The large quantity of rainfall in the Rainforest MOE creates many surface water features that present an obstacle to ground mobility. These features include rivers, creeks, ponds, lakes, swamps, and seasonally flooded lowlands.

d. Topography (Landform, Slope, Relief, Roughness).

Topography is of primary concern for cross-country mobility of both Soldiers and equipment. It may also affect sensors, artillery effectiveness, communications, concealment, and detectability (see also reference 20).

2.1.3 Biological Factors.

a. Both microbes and macro-organisms present potential problems to military operations including human injury and disease, spoilage of perishable items, fouling of equipment, and bio-deterioration of materiel.

b. Microorganisms.

Microbes are the major agent of biodegradation and a cause of human disease. Microbe species have evolved to attack all naturally occurring compounds and many synthetic materials. Microbes may oxidize metal pipes causing corrosion or foul lubricating grease in equipment causing excessive wear. Optics, sensors, canvas, and other cloth items may be damaged by the growth of algae or fungi on glass. Microorganisms can colonize susceptible materials and utilize them as food sources. Such attacks usually result in marked deterioration of the physical properties of the materials. Also, fungi can grow on surface contaminants which find their way into materials during manufacture and use. Optical paths can be blocked by growth on lenses and prisms. Accumulations of growth can block the movement of delicate or small parts. Fungal mats may cause unwanted conduction paths in electrical systems. Metabolic waste from insects may damage the exposed items by acting as a substance for microbial attack (see also reference 11).

c. Macro-organisms.

(1) Damage caused by macro-organisms range from nuisance to destructive through direct contact (chewing, eating, moving, nesting, burrowing). For example, termites are an important group of macro-organisms capable of the physical and chemical breakdown of plant material and, as such, they are a factor in the degradation of cellulose-containing test materials.

(2) Insects are abundant in the tropics and can be harmful to building materials. Exposed items, in many instances, serve as food and as habitat for a variety of insects. Metabolic waste from these insects may damage the exposed items through the action of organic acids or by acting as a substance for microbial attack. Termites, particularly the subterranean Formosan variety, are perhaps the most serious threat to buildings in the tropics. These insects can rapidly destroy a wood building, and cause severe damage to electrical equipment (reference 6). Termite damage to both natural and synthetic materials has long been recognized as a serious problem. Another example is roaches: They can do extensive damage to textiles and

certain synthetic polymers such as silicon rubber. Even though roaches are not capable of digesting cellulose or silicon-based polymers, they can obtain nutrition from contaminants adhering to or microorganisms growing on the material. Many insects which do not attack materials directly may influence equipment performance through nest building activities.

(3) Insects and parasites present great threat to human health. Some parasites cause disease or injury directly. Parasites like mosquitoes, fleas, ticks, leeches, and kissing bugs act as vectors for many tropical diseases. They also create injuries that can become infected.

d. Dense Vegetation.

(1) The tropical vegetation restricts visibility and mobility, particularly in the rainforest.

(2) Dense vegetation may be an obstacle to mobility (Soldier and vehicles), visibility, radars, communications, sensors, and weapons systems (see also reference 19). On the other hand, it may provide cover for covert operations. Some types of vegetation tend to exude tannins, sugars, and other natural plant products, which may support microbial growth and corrosion processes.

2.2 Test Site Severity.

a. The Determination of Optimun Tropic Storage and Exposure Sites efforts[22, 23] reported results of materials exposures in the Republic of Panama. The objectives of the investigations were to: (a) determine whether weathering tests could be speeded up by identifying the most severe sites, (b) determine deterioration rates and patterns of six basic materials, and (c) determine the effects of tropic wet and dry seasons on deterioration.

b. Six basic materials representing three general material classes (textiles, materials, and rubber) were used as indicators of site severity. These basic materials were cotton, polyvinyl chloride (PVC), nylon, latex rubber, butyl rubber, and mild steel. The test sites consisted of open, forested, sheltered, and coastal sites located on the Pacific coast, Atlantic coast, approximately at Mid-Isthmus, and one air-conditioned control site. Following are results obtained in this study:

(1) The degree of severity in deteriorative properties of a tropic exposure site is dependent on the material being exposed. For example, a site that is severely degrading for cotton may be slow degrading for mild steel.

(2) The Atlantic and Pacific sides of the Isthmus provided exposure modes and sites equally severe on a representative cross section of types of materials, except for steel. Therefore, site selection for exposure tests need not be based on an assumed relationship between the amount of rainfall at a potential exposure location and deterioration severity.

(3) It is possible to increase the severity of natural tropic exposure tests by careful selection of sites. This conclusion is based on reliable statistical differences in deterioration rates that exist among environmental exposure modes in geographic proximity.

(4) Corrosion weight loss and tensile strength are highly-related indices of site severity on steel. Corrosion weight loss and tensile strength could be substituted for each other as measures of site severity on steel in certain cases.

c. A methodology investigation[24], conducted at TRTC, reported results of exposing materiel items in the Republic of Panama at different exposure sites and modes; these items were tested at regular intervals. The objectives of the study were to learn how and when to measure test item performance and to relate performance measures to visual evidence of deterioration. Basis for selection of items included measurable performance characteristics, hypothesized susceptibility to tropic deterioration, and common Army usage. The exposure modes for these items were selected to be representative of long-term combat storage conditions.

d. Significant deterioration in performance was most apparent for items exposed in the pallet - and tarpaulin - forest exposure modes. Most items required at least 6 months for significant deterioration to be discernible. Corrosion was the primary deterioration agent for material studied in the investigation, and was most rapid and severe in the pallet- and tarpaulin - forest exposure modes.

e. There was no evidence that microbial growth or insect infestation were related directly to material or performance deterioration of the items exposed to the humid tropic environment. However, it was evident that they indirectly contributed to the corrosive process by causing the deterioration or, in some cases, the total destruction of the boxes in which the test items were packaged.

f. Visual evidence of exterior item deterioration from tropic exposure does not assure that item performance has degraded nor does the lack of exterior deterioration assure the absence of performance degradation.

g. For further information regarding results from these accelerated exposure tests, see reference 11, pp IV-11 - IV-17.

2.3 Tropical Region's Effects on Military Materiel.

During the life-cycle and use of military materiel, issue and operational use may include intermediate stages of field storage or maintenance and reissue before ultimate consumption or disposal, and operational use may include storage (stowage) and installation on vehicles or other transportation modes. Throughout this sequence, adverse environmental effects can and do affect the condition, operation, and effectiveness of the materiel.

2.3.1 General Effects on Materials.

a. Plastics and rubbers.

(1) PVC pipes are not ultraviolet (UV)-resistant; therefore, they must not be used above ground and exposed to sunlight even during brief storage periods. If use of an alternative material is not possible and PVC must be used above ground, two coats of paint compatible with PVC must be applied to minimize the exposure effects. Acrylonitrile-butadiene-styrene (ABC) piping is UV-resistant and is used for exposed applications (see reference 6).

(2) Plastics are generally not affected by constant exposure to burrowing and nesting insects, molds and mildew problems as encountered by wood product and materials, but constant exposure to UV solar radiation can cause structural failures ranging from delamination in fiber-reinforced resinous materials (fiberglass) to actual chemical and physical breakdowns in certain plastics such as PVC. In laminated materials, repeated cyclic stresses, impact, and so on can cause layers to separate, forming a mica-like structure of separate layers, with significant loss of mechanical toughness (see reference 6).

(3) Most basic polymers are not susceptible to attack, but additives increase vulnerability. Studies conducted found that the amount of fungal growth was dependent on the amount of non-rubber constituents present. Leaching of natural rubber to remove non-rubber soluble components decreased susceptibility to fungal growth. PVC is almost 100 percent inert to fungi. PVC will not support fungal growth, but when plasticizers, stabilizers, and processing agents are added, it can become susceptible to fungal growth (see reference 11).

(4) Termites attack polymers such as PVC. Two US Naval Research Laboratory efforts[25, 26] exposed a number of PVC formulations, with different plasticizers with and without toxicants, to termites in the humid tropics. Formulations plasticized with dioctyl phthalate were the most heavily attacked even when they contained toxicants. Formulations plasticized with tricresyl phosphate fortified with the ortho-isomer were the least damaged, either with or without toxicants present, although formulations with the para-isomaer were nearly as good. The toxicant Lindane was found to be most effective and Dieldrin the least effective in preventing termite attack. Physical modifications to PVC such as surface smoothness, increase thickness, and incorporation of mineral fillers provided modest to considerable improvement in resistance. There was a correlation between hardness and termite resistance. Increasing hardness from 10 to 30 percent (Shore type D durometer scale) reduced the number of PVC failures by 86 percent. The soft flexible polymers, ethylene propylene rubber, and clorosulfonated polyethylene were found to be more resistant to termite attack than the softest PVC (see also reference 11).

(5) Other plastics (such as acrylics and polycarbonates) used in exterior applications such as signage and glazing are UV-resistant. Fiberglass materials are not UV-resistant. After prolonged exposure to sunlight, they fade, and delaminate (see reference 6).

b. Protective coatings.

In the tropics, exterior coatings encounter more destructive influences than those used on interiors. The deteriorative agents consist of extremes of temperature, moisture, sunlight, and reactive gaseous elements of the atmosphere (oxygen, ozone, sulfur dioxide, hydrogen sulfide); marine exposure (e.g. salt spray); abrasive materials (e.g. sand, dust, and dirt carried by winds and water); and biological agents such as fungi, bacteria, insects and marine organisms. Further contributions to deterioration may occur when the surface to be coated may have porous, acid or alkaline, oily or resinous characteristics. The maximum decorative properties of a coating are usually observed immediately after a coating has dried. However, the maximum protective qualities of the coating required a week to several months to develop. Deterioration begins shortly after application or after exposure to the particular deteriorative conditions. Because the process is slow, the reactions have usually been in progress for some time before they produce visible effects. Moisture and UV radiation are considered the two most degrading factors. Deterioration can be observed as discoloration, loss of gloss, chalking, cracking and alligatoring. For further information regarding results from research studies conducted on protective coating systems, e.g. epoxy, vinyl, latex enamel, acrylic, and alkyd paints, see reference 11.

c. Wood.

(1) Wood material and products in the tropics are subjected to constant exposure to moisture from humidity, rain, and wind-blown spray. Additionally, burrowing and nesting insects, molds and mildew, and various forms of rot are constant problems (see reference 6).

(2) In the tropics, all cellulosic materials are degraded by two forms of biological activity, microbial and termite attack. Rotting is the natural decay caused by microbial and termite attack from the many varieties of fungi in the tropic soil and air. Termite attack results in rapid destruction of cellulose materials in humid tropic regions.

(3) In a study conducted by the Naval Research Laboratory[27] 115 natural woods and five wood preservatives were evaluated for resistance to subterranean termites and to above and below-ground fungal decay. Of the 115 species of untreated wood, 37 survived the full 158 month exposure. Of these, only five were considered to be highly resistant to all wood-degrading organisms present: 1) Guajacum officinale (Lignum vitae), 2) Dalbergia retusa (Cocobolo), 3) Vouacupoua Americana (Acapu), 4) Chlorocardium rodiei (Greenheart), and 5) Tabebuia guayacan (Guayacan). Fungi below and near the ground-line were the most universally destructive organisms. On preservative treated wood, no termite attack was observed on either creosote or pentachloro-phenol-treated specimens during the 18 month test periods (see reference 11).

d. Metals.

(1) General Design Considerations. Since most metals deteriorate as a result of exposure to the action of oxygen, water, vapor, carbon dioxide, salt and other chemical substance, the use of metals in tropical area construction requires careful consideration. High humidity and the heavy concentration of salt in the air, soil, and water in the tropics, provide an ideal environment for metal corrosion to occur. Protection of all metals from these conditions is critical (see reference 6).

(2) The primary mechanism of degradation of metals in the tropic regions is corrosion.

(3) There are several kinds of corrosion, each of which is caused by the interaction of as many as 30 to 40 factors. Oxygen is the main contributor to corrosion of metals such as aluminum, magnesium, copper, steel, and zinc. Some of the oxides formed are beneficial because they prevent further corrosion by forming thin films on the metal which prevent or retard further reaction. This is true in aluminum, chromium, nickel, and various stainless steels. The formation of such oxides (in the case of aluminum and its alloys) by commercial process called anodizing produces an extremely adherent and abrasion resistant surface coating of aluminum oxide. Oxidation or rust produced on mild steels can be caused by direct combination with atmospheric oxygen, but such attack is slow at low temperatures. For rapid corrosion of iron and steel, the presence of moisture and elevated ambient temperatures is essential. With water present, either as a liquid or a vapor, a fast chemical reaction takes place and one or a number of possible oxides of iron are formed. As noted, the oxides of aluminum and some other metals prevent further corrosion but such an effect is rarely observed with iron and non-stainless steels. The reason for this is that oxides of aluminum and other resistant metals are crystalline and occupy the same area as base metals; there is no overcrowding of the surface and, therefore, the oxide crystals sheath the base metal. With iron and low alloy steels, the corrosion products occupy a greater area than the base metal and do not form an impervious film. The corrosion products fall off resulting in exposure of new material to attack. For additional information regarding tensile strengths loss over time for specific metals exposed to the tropical environment see reference 11, ppV-31 - V-39.

2.3.2 Effect on Military Material.

a. Each class of military equipment is affected differently by the various MOEs in the humid tropic regions, and these factors can vary considerably from place to place, and from season to season. However, there are certain environmental factors that should be considered important for field testing in the development of equipment for the humid tropic regions.

b. Below is a list of classes of military equipment; following each class, are the associated environmental risk factors of the humid tropic regions that should be considered in the development of that equipment. Factors indicated by **bold font** are considered high risk, which represents a high probability of that class of equipment encountering problems in a given environment due to that environmental factor. Those not in bold are considered medium risk, which represents a medium probability of that class of equipment encountering problems in a given environment due to a particular environmental factor. See Table 2, Risk Summary for Tropic Regions Environmental Factors (provided by the Natural Effects Test Office (NETO), US Army Yuma Proving Ground), which also lists the low-risk factors for the classes of equipment listed below.

(1) Soldier Equipment (Clothing).

(a) High Temperature. Although not usually a risk factor for the clothing, a Soldier's clothing must provide protection from the sun and wind and allow sufficient thermoregulation by ventilation for convection cooling, and evaporative heat loss (sweat evaporation). Mission Oriented Protective Posture (MOPP) gear, Battle Dress Overgarment (BDO), and body armor can exacerbate heat stress caused by a hot environment and/or the work performed by the wearer by reducing the Soldier's capacity for evaporative heat loss which can increase the likelihood of heat-stress casualties.

TABLE 2. RISK SUMMARY FOR TROPIC REGIONS ENVIRONMENTAL FACTORS

FACTORS		Soldier Equipment - Clothing	Soldier Equipment - Portable Electronic Equipment	Wheeled Vehicle, Tracked Special Purpose Vehicles	Unmanned Ground Vehicles	Direct Fire Weapons	Indirect Fire Weapons	Small Arms and Automatic Weapons	Ammunition and Explosives	Missiles and Rocket Systems	Electronics, C4ISR	Aviation - Manned Aircraft	Aviation - Parachutes	Aviation - Unmanned Air Systems	CBRN	Construction and Service Equipment	Watercraft	General Supplies and Equipment	General Supplies and Equipment (Tents/Shelters)	General Supplies and Equipment (Food Preparation and Storage)
		CLASSES OF MILITARY EQUIPMENT																		
ATMOSPHERIC FACTORS	High Temperature	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Medium	Medium	Medium	Low	Medium	Medium	Medium
	Low Temperature	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Precipitation (Medium to Heavy Rain)	High	High	Medium	High	Medium	Low	High	Low	Medium	High	Medium	Medium	Medium	High	Low	Low	Medium	High	Medium
	Precipitation (Freezing Rain, Hail, Snow)	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Constant High RH	High	High	Low	High	Low	Low	Low	High	Medium	High	Medium	Medium	Medium	High	Low	Low	Medium	High	Medium
	Cyclic RH	Medium	Medium	Low	Medium	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium
	Low RH	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Fog/Ice Fog/White Out	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	High Wind	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	Medium	Low	Low	Low	Medium	Medium	Medium
	Salt/Salt Fog (Corrosion)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	Solar Radiation	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Low
	High Elevation	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	Medium	Low	Low	Low	Low	Low	Medium
TERRAIN FACTORS	Landforms (Steep Slope, Relief, Roughness)	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Medium	Low	Low	Low	Low
	Exposed Rock	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Sand	Low	Low	Medium	Medium	Low	Low	High	Low	Low	Medium	Medium	Medium	Medium	Low	Medium	Low	Low	Low	Low
	Mud	Medium	Medium	Medium	Medium	Low	Medium	High	Medium	Low	Medium	Low	Low	Low	Medium	High	Low	Medium	Medium	Medium
	Dust	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Surface Water	Medium	Medium	Medium	Medium	Low	Medium	High	Medium	Low	Low	Low	Low	Low	Low	Medium	High	Low	Low	Low
	Frozen Soil	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Surface Snow Ice	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
BIOLOGICAL	Dense Vegetation	High	High	Low	High	Medium	Medium	High	High	High	High	Low	Medium	High	High	High	Low	Medium	Medium	Low
	Micro/Macro Biological Organisms	Medium	High	Medium	High	Low	Low	High	High	Low	High	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Medium

High Risk (Test Required) | Medium Risk (Test Recommended) | Low Risk (No Requirement)

(b) **Precipitation - Rain**. The prolonged presence of water creates an environment favorable to fungal and microbial activity. This can cause weakening, fading, and rotting of clothing.

(c) **Constant High RH**. High RH prevents material from drying. The prolonged presence of moisture creates an environment favorable to fungal and microbial activity. This can cause weakening, fading, and rotting of clothing.

(d) Cyclic RH. Temperature- humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Landform (relief, roughness). Irregular topography causes wear and tear on Warfighters' combat uniforms during kneeling, prone, and squatting positions.

(g) Mud. Rot accelerates when moisture is trapped providing food for microorganisms.

(h) Surface Water. The prolonged presence of water creates an environment favorable to fungal and microbial activity. This can cause weakening, fading, and rotting of clothing.

(i) **Dense Vegetation**. The abundant thorns and spines combined with the density of plants and trees can damage clothing. Many plants and trees also exude sugary sap that will accelerate microbial decay.

(j) Micro/Macro-Organisms. As the primary agent of decay in these MOEs, microbes and fungi are capable of digesting virtually any organic and some inorganic materials. Fabrics that remain damp are ideal habitat for mold and other microorganisms even if they cannot consume the fabric. Furthermore, rodents seek dry places and will chew in, on, and through and nest in clothing in storage.

(2) Soldier Equipment (Portable Electronic Equipment).

(a) High Temperature. Affects sight systems, guidance systems, electronics, and long-term life of plastic and rubber parts and displays, and causes electronic breakdowns.

(b) **Precipitation - Rain**. Devices may be vulnerable to infiltration of water during frequent rains. Both radio frequency (RF) and electro-optical signals can be attenuated by water. These devices may have limited range and functionality during heavy rain.

(c) **Constant High RH**. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi, and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials and may alter interior and exterior electrical properties.

(f) Landform (steep slope, relief, roughness). In low areas such as valleys or canyons, landforms can reduce the operating range of radios. Radio range can be enhanced if operated from a hilltop or ridge and communicating with a receiver in open terrain. In tight canyons and deep ravines, Global Positioning System (GPS) equipment can have difficulty finding a sufficient number of satellites for necessary accuracy, or in the worse case, may fail to acquire enough satellites to establish position, also satellite lock can be unstable.

(g) Mud. Any openings in materiel are vulnerable to penetration by mud. Ports or other intakes can become clogged and unusable. The moisture associated with mud can also damage electronics.

(h) Surface Water. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. These devices may have limited range and functionality during heavy rain.

(i) **Dense Vegetation**. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality.

(j) Micro/Macro-Organism. As the primary agent of decay in these MOEs, microbes and fungi are capable of digesting virtually any organic and some inorganic materials, including rubber and some plastics. They will also grow wherever they can find water and nutrition. They may grow on circuits and create shorts, or on lenses or prisms of optical and electro-optical devices.

(3) Wheeled Vehicle, Tracked Special Purpose Vehicles.

(a) High Temperature.

1 High ambient temperatures reduce ability of automotive components to shed heat through their lubrication and cooling systems, e.g., engine, transmission, transfer, differential, final drives. Ground temperatures can reach up to 74 °C (165.2 °F) and can stress automotive components further. The lubricant seals can break down, and the lubricants can fail

exacerbating the problem. Batteries do not hold their charge efficiently in high temperatures. High temperatures also increase rubber/metal separation on road wheels.

2 Crew compartments must be well ventilated to purge the heat gained from solar, electronics, hydraulics, the engine, and other sources of heat. During tests of tracked, armored infantry vehicles, personnel compartment temperatures could be between 8 to 10 °C (46.4-50 °F) above the prevailing ambient temperature, causing considerable crew discomfort. High ambient temperatures, solar radiation heating and heat from engines and transmissions cause discomfort and fatigue of operating personnel.

(b) Precipitation - Rain. The prolonged presence of water creates an environment favorable to fungal and microbial activity. This can cause weakening, fading, and rotting of materials.

(c) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(d) Landform (steep slope, relief, roughness). Due to rapid weathering in the tropics, slopes may be at or above the angle of repose creating serious challenges for mobility.

(e) Mud. With an ample supply of finely weathered sediments and water, mud is an almost certain occurrence in the tropics. However, it is usually covered by a thin layer of organic debris; when it is disturbed, muddy conditions ensue and mobility is reduced. Mud may also clog intakes, impair function of moving parts or accelerate corrosion by sealing moisture onto a surface.

(f) Surface Water. Rivers, streams, ponds, lakes, and swamps are common in the tropics and can affect mobility.

(g) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture, and foul lubricants.

(h) Sand. Sand contaminates bearings and lubricating systems and, when mixed with oil, forms an abrasive paste.

(4) Unmanned Ground Vehicles.

(a) High Temperature. High ambient temperatures reduce ability of automotive components to shed heat through their lubrication and cooling systems, e.g., engine, transmission, transfer, differential, final drives. Ground temperatures can reach up to 74 °C (165.2 °F) on hot days and can stress automotive components further. The lubricant seals can break down, and the lubricants can fail exacerbating the problem. Batteries do not hold their charge efficiently in high temperatures. High temperatures also increase rubber/metal separation on road wheels. Interior compartments for electronics and controls must be well ventilated to purge the heat gained from solar, electronics, hydraulics, the engine, and other sources of heat.

(b) **Precipitation - Rain**. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. These devices may have limited range and functionality during heavy rain.

(c) **Constant High RH**. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Landform (steep slope, relief, roughness). In low areas such as valleys or canyons, landforms can reduce the operating range of guidance transmission and receiver, or optical path guidance. Radio range can be enhanced if operated from a hilltop or ridge when transmitting to a receiver in open terrain. In tight canyons and deep ravines, GPS guidance equipment can have difficulty finding a sufficient number of satellites for expected accuracy or, in the worse case, may fail to acquire enough satellites to establish position; also, satellite lock can be unstable. Unless the vehicle is designed with steep ingress and egress angles needed for negotiating the deep and steep banked channels, mobility can be difficult.

(g) Mud. With an ample supply of finely weathered sediments and water, mud is an almost certain occurrence in the tropics. However, it is usually covered by a thin layer of organic debris. When disturbed, muddy conditions ensue and mobility is reduced. Mud may also clog intakes, impair function of moving parts or accelerate corrosion by sealing moisture onto a surface.

(h) Surface Water. Rivers, streams, ponds, lakes, and swamps are common in the tropics and can affect mobility.

(i) **Dense Vegetation**. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation, these devices may have limited range and functionality. Vehicular movement through dense vegetation in the humid tropics is very difficult or more often impossible. Travel is usually restricted to roads.

(j) Micro/Macro-Organisms. Vegetation interferes with optical path guidance and can reduce mobility in areas with heavy growth. Rodents can bite insulation from unprotected wires which allows bare conductors to touch and short out.

(k) Sand. Sand contaminates bearings and lubricating systems and, when mixed with oil, forms an abrasive paste.

(5) Direct Fire Weapons.

(a) High Temperature.

1 High ambient temperatures increase cooling time for gun tube or restricts firing rate. Refraction, or optical path bending, may cause problems for tank crews attempting engagements at ranges beyond 1,500 meters. Anytime heat shimmer is present, refraction may also exist. The effect of refraction is to make the target appear lower during the day; the sight picture, though it appears center of visible mass to the gunner, is actually below the target. This may result in a short round. At night, the effects are the opposite and may result in over shooting the target. Propellant in tank ammunition can become more energetic when heated causing a change in the ballistic trajectory.

2 High ambient temperatures reduce ability of automotive components to shed heat through their lubrication and cooling systems (e.g., engine, transmission, transfer, differential, and drives). Ground temperatures can reach up to 74 °C (165.2 °F) and can stress automotive components further. The lubricant seals can break down, and the lubricants can fail, exacerbating the problem. Batteries do not hold their charge efficiently in high temperatures. High temperatures also increase rubber/metal separation on road wheels. Interior compartments for electronics and controls must be well ventilated to purge the heat gained from solar, electronics, hydraulics, the engine, and other sources of heat.

(b) Precipitation - Rain. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. These devices may have limited range and functionality during heavy rain.

(c) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(d) Dense Vegetation. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. If firing through dense vegetation, explosive rounds can detonate prematurely due to the extra mass of vegetation.

(6) Indirect Fire Weapons.

(a) High Temperature.

1 High ambient temperatures increase cooling time for the gun tube, or restricts firing rate. Propellant can become more energetic when heated causing a change in the ballistic trajectory.

2 On self-propelled weapons, high ambient temperatures reduce ability of automotive components to shed heat through their lubrication and cooling systems (e.g., engine, transmission, transfer, differential, and drives). Ground temperatures can reach up to 74 °C (165.2 °F) and can stress automotive components further. The lubricant seals can break down, and the lubricants can fail, exacerbating the problem. Batteries do not hold their charge efficiently in high temperatures. High temperatures also increase rubber/metal separation on road wheels. Interior compartments for electronics and controls must be well ventilated to purge the heat gained from solar, electronics, hydraulics, the engine, and other sources of heat.

(b) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(c) Mud. With an ample supply of finely weathered sediments and water, mud is an almost certain occurrence in the tropics. However, it is usually covered by a thin layer of organic debris. When the surface is disturbed, muddy conditions ensue. Mud may also clog intakes, impair function of moving parts or accelerate corrosion by sealing moisture onto a surface.

(d) Surface Water. Rivers, streams, ponds, lakes, and swamps are common in the tropics and can affect mobility.

(e) Dense Vegetation. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. Vehicular movement through dense vegetation in the humid tropics is very difficult or more often impossible. Travel is usually restricted to roads.

(7) Small Arms and Automatic Weapons.

(a) **Precipitation - Rain**. Devices may be vulnerable to infiltration of water during frequent rains. Infiltration by water may cause corrosion and jamming may be caused by other debris in water.

(b) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(c) **Mud**. With an ample supply of finely weathered sediments and water, mud is an almost certain occurrence in the tropics. However, it is usually covered by a thin layer of organic debris. Mud may also clog intakes, impair function of moving parts or accelerate corrosion by sealing moisture onto a surface.

(d) **Surface Water**. Rivers, streams, ponds, lakes, and swamps are common in the tropics and are another source for corrosion.

(e) **Dense Vegetation**. Range of weapons may be severely limited by dense vegetation.

(f) **Micro/Macro-Organisms**. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture on a surface, and foul lubricants.

(g) **Sand**. Sand can enter the weapon and gun bore, or can be carried into the gun by belted ammunition and can cause parts to jam, a projectile to stick, or cartridge case to fail to eject. Sand settles on moving parts and acts as an abrasive.

(h) High Temperature. High temperatures can lead to small arms weapon cookoff conditions (where the barrel/chamber get so hot the propellant automatically ignites) leading to a runaway weapon.

(8) Ammunition and Explosives.

(a) High Temperature. Ammunition becomes more energetic when heated causing a change in ballistic trajectory. Sensitivity of explosives increases as well as explosive power. Ammunition components, like ammonium nitrate, liquefy and exude.

(b) **Constant High RH**. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing swelling or making explosives damp and more likely to fail.

(c) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(d) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(e) Mud. Mud may also clog barrels or accelerate corrosion by sealing moisture onto a surface.

(f) Surface Water. Rivers, streams, ponds, lakes, and swamps are common in the tropics and are another source for corrosion.

(g) **Dense Vegetation**. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. If firing through dense vegetation, explosive rounds can detonate prematurely due to the extra mass of vegetation.

(h) **Micro/Macro-Organisms**. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture.

(i) Solar Radiation. Additional thermal loading from sunlight can increase temperatures significantly. Some substances may deteriorate and become unstable with UV exposure.

(9) Missile and Rocket Systems.

(a) High Temperature. Affects sight systems, guidance systems, electronics, long-term life of plastic and rubber parts and displays, and causes electronic breakdowns.

(b) Precipitation - Rain. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. During heavy rain, these devices may have limited range and functionality.

(c) Constant High RH. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Dense Vegetation. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. If firing through dense vegetation, missiles can detonate prematurely due to the extra mass of vegetation.

(10) Electronics; Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR).

(a) High Temperature. Long-term life of plastic and rubber parts and displays are reduced. Electronic breakdowns occur more frequently.

(b) **Precipitation - Rain**. Devices may be vulnerable to infiltration of water during frequent rains. Rain can cause an electrical shock hazard for exposed circuitry of these items. Both RF and electro-optical signals can be attenuated by water. During heavy rain, these devices may have limited range and functionality.

(c) **Constant High RH**. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) **Dense Vegetation**. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. Vehicular movement through dense vegetation in the humid tropics is very difficult or more often impossible. Travel is usually restricted to roads. Propagation of radio frequency energy in a tropic environment presents a special problem because dense vegetation results in high signal loss. Many Department of Defense (DOD) agencies have conducted extensive research on electromagnetic wave propagation in tropic environments. These investigations have attempted to develop mathematical models that permit predictions regarding the influence of tropic environments on propagation losses, and have provided detailed information on such environmental parameters as vegetation density and topography. Some of these studies are presented as follows:

1 US Army Tropic Test Center (USATTC) conducted a study to establish standard radio frequency propagation courses for future use in evaluating newly developed radio communications system[28]. In addition, mathematical models developed by other DOD organizations were evaluated to determine their usefulness in predicting path loss in radio tests.

a Two test areas were selected for use in establishing standard radio frequency propagation courses. One area, Coco Solo, is located on the Atlantic side of the Isthmus of Panama; the other, Gamboa, is located at Mid - Isthmus.

b The field strength 15 meters from the transmitter was measured at the beginning and end of each day and used radiated power term in computation in path losses. Two path loss values- one referenced to the field strength at 15 meters and one referenced to a radiated power of 1 watt - were computed along each radial for each of the four frequencies used in this study.

c Conclusions:

► Available mathematical models were too general, and were difficult to use in predicting precise path loss, and would not be applicable to future tests.

► Path losses measured at the Gamboa and Coco Solo receiver / transmitter sites are repeatable. This indicates that the methodology employed is adequate for use in future radio tests.

► Path loss increase with increasing distance, forest density, soil salinity, and transmitter frequency.

► Rough terrain and non-uniform vegetation contribute to variable path loss measurements between sites that are geographically very close together.

2 High Frequency (HF) and Very High Frequency (VHF) Propagation Efficiencies.

a In 1964, evaluations were made on the effects of dense jungle growth, hilly terrain, noise and local interference on HF and VHF radio propagation in the jungle areas around Chepo, Republic of Panama. Vertical and horizontal antenna efficiencies and techniques applicable to installations in rain forests were also investigated. The purpose of the test was to improve jungle communications by formulating methods applicable to utilization of antennas and antenna installation equipment that could be useful to small jungle patrols.

b During dry season, several tests were conducted. The terrain between receiving sets was varied: open grassland, jungle with and without canopy, along roads, over hills. Different antenna lengths and heights above ground were investigated for clearness of reception. It was found that dense undergrowth reduced signal strength much more than in temperate zone forests, but if antennas were elevated 8 meters or more above ground, receptions were quite satisfactory. When one reception point is low with respect to surrounding terrain, it was suggested that raising the antennae 15 or 18 meters or retransmitting be employed. Recommendations were made that use of VHF be improved because there was no interference as with HF.

3 RF Propagation by Satellite. From 1967 to 1970, the US Air Force (USAF) Cambridge Laboratories conducted signal attenuation studies at USATTC[29]. The studies had two objectives: determination of ionospheric effects at very high frequency, and determination of foliage effects on VHF satellite signals. Two sites were established: one in a tropical moist forest and one in the open. One satellite was synchronous and two were in polar orbit. Results showed that attenuation of a 40 megahertz (MHz) signal caused by the jungle canopy at low angles (less than 30 degrees) was 3 to 6 decibels (dB). There was no measurable difference between forest and open sites at elevation angels greater than 40 degrees at 136 MHz.

(g) **Micro/Macro-Organisms**. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture, and foul lubricants.

(h) Solar Radiation. Equipment may obtain surface temperatures of greater than 60 °C (140 °F) which can affect electronics and long-term life of plastic and rubber parts and displays, and cause electronic breakdowns.

(i) Sand, Mud, and Dust. These conditions could cause problems for the operation of radios, networks, routers, etc.

(11) Aviation (Manned Aircraft).

(a) High Temperature. High temperatures on and near the ground may seriously affect aircraft operations. The reduction in air density caused by elevated temperatures reduces the lift capability of the aircraft such that combat range, cargo capacity, or munitions loads may have to be decreased. The light structures of the aircraft heat rapidly from the effects of high ambient air temperature and solar radiation, especially when the aircraft is on the ground. Enclosed, poorly ventilated spaces can reach very high temperatures affecting weapons systems and electronic elements that are in these enclosed areas, and long-term life of plastic and rubber parts and displays.

(b) Precipitation - Rain. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. During heavy rain, these devices may have limited range and functionality.

(c) Constant High RH. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Landform (steep slope, relief, roughness). Takeoff and landing areas for fixed-wing aircraft must be relatively flat and nearly level, and with few obstacles in the direction of the flight path. Landform suitable for takeoff and landing should be oriented in the direction of the prevailing wind for the area.

(g) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture, and foul lubricants.

(h) Sand. When ingested into the engine, sand can erode high-speed engine parts which will degrade engine performance. During takeoff and landing of rotary-wing aircraft on loose soil composed of sand, visibility can be reduced to zero in a brownout condition, making those maneuvers extremely hazardous. Dust can cause rapid wear of the leading edges of the rotors when the aircraft must fly within 152 meters of the ground. Sand settles on moving parts and acts as an abrasive. Sand contaminates bearings and lubricating systems and, when mixed with oil, forms an abrasive paste.

(i) Solar Radiation. Equipment may obtain surface temperatures of greater than 60 °C (140 °F) which can affect electronics and long-term life of plastic and rubber parts and displays, and cause electronic breakdowns.

(j) High Wind. High surface winds in the vicinity of some terrain features can cause turbulence at altitude. Strong headwinds can cause high fuel consumption.

(k) High Elevation. Air density is lower at high elevation which limits load capacity of the aircraft.

(12) Aviation (Unmanned Air Systems).

(a) High Temperature. High air temperature results in low density-altitude, which limits payload capacity and service ceiling; affects electronics and long-term life of plastic and rubber parts and displays, and causes electronic breakdowns.

(b) Precipitation - Rain. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. During heavy rain, these devices may have limited range and functionality.

(c) Constant High RH. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature- humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) **Dense Vegetation**. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality.

(g) **Micro/Macro-Organisms**. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture, and foul lubricants.

(h) Sand. When ingested into the engine, sand can erode engine parts which will degrade engine performance. Sand can cause rapid wear of the leading edges of the rotors when the aircraft must fly within 152 meters of the ground. Sand settles on moving parts and acts as an abrasive. Sand contaminates bearings and lubricating systems and, when mixed with oil, forms an abrasive paste.

(i) Solar Radiation. Equipment may obtain surface temperatures of greater than 71 °C (159.8 °F) which can affect long-term life of plastic and rubber parts and displays, and cause electronic breakdowns.

(j) High Wind. High surface winds in the vicinity of some terrain features can result in turbulence at different altitudes. Strong headwinds can cause high fuel consumption.

(k) High Elevation. Air density is lower at high elevation which limits load capacity of the aircraft.

(13) Aviation (Parachutes).

(a) Precipitation - Rain. Parachutes may be vulnerable to infiltration of water during use or storage. The added weight of water may reduce load capacity.

(b) Constant High RH. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(c) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, and change elasticity or plasticity.

(d) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(e) Landform (steep slope, relief, roughness). Preferred parachute drop zones must be relatively flat, level, and free from abrupt terrain obstacles.

(f) Dense Vegetation. Locating a suitable drop zone in uninhabited areas may present a challenge.

(g) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture.

(h) Sand. Sand infiltration in the parachute pack can chafe the parachute fabric and fray the shroud lines.

(i) Solar Radiation. Equipment may obtain surface temperatures of greater than 60 °C (140 °F), which can affect electronics and long-term life of plastic and rubber parts.

(j) High Wind. This may cause difficulty in landing on target or an uneven distribution of weight leading to undue wear on fabric and shroud lines. It can cause instability of the payload as it contacts the ground.

(k) High Elevation. Air density is lower at high elevation which limits load capacity.

(14) Chemical, Biological, Radiological, Nuclear (CBRN).

(a) High Temperature. Affects long-term life of plastic and rubber parts and displays, and causes electronic breakdowns. Chemical reagents and decontamination solutions break down and lose their effectiveness.

(b) **Precipitation - Rain**. Devices may be vulnerable to infiltration of water during frequent rains. Both RF and electro-optical signals can be attenuated by water. During heavy rain these devices may have limited range and functionality.

(c) **Constant High RH**. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Mud. Mud may clog intakes on monitoring equipment or seal moisture onto a surface accelerating corrosion.

(g) **Dense Vegetation**. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. Movement through dense vegetation in the humid tropics is very difficult or more often impossible. Travel is usually restricted to roads. Abundant thorny vegetation may present a threat to some personal protective equipment (PPE). Degradation of vegetation produces alcohols that cause false positive (nerve agent) detections.

(h) **Micro/Macro-Organisms**. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture, and foul lubricants.

(i) Solar Radiation. Equipment may obtain surface temperatures of greater than 71 °C (159.8 °F) which can affect electronics and long-term life of plastic and rubber parts and displays, and cause electronic breakdowns.

(15) Construction and Service Equipment. This class of military equipment includes equipment with a very wide range of characteristics such as:

- Tractors, cranes and road construction equipment
- Water treatment systems
- POL storage and distribution equipment
- Air compressors, pumps, and welders
- Electric power generating equipment
- Air conditioning, refrigerating equipment, and fans

Much of this equipment is engine-driven and thus subject to the same environmental problems as vehicular materiel. In many instances, engine enclosures are utilized on this portable equipment to provide weather protection, reduce noise, or prevent IR radiation; however, great care must be exercised to ensure that such enclosures do not impose overheating problems at high ambient temperatures and that cooling air for the enclosed engine or radiator is adequately filtered to prevent clogging of cooling fins and that it is of adequate volume. It should be recognized that stationary equipment, even though portable, must be fan-cooled and may be adversely affected by ambient wind direction, as well as velocity.

(a) High Temperature. High ambient temperatures reduce ability of automotive components and stationary equipment to shed heat through their lubrication and cooling systems, for example, engine, transmission, transfer, differential, and drives. Ground temperatures can reach up to 74 °C (165.2 °F) on hot days and can stress automotive components further. The lubricant seals can break down, and the lubricants can fail, exacerbating the problem. Batteries do not hold their charge efficiently in high temperatures. High temperatures also increase rubber/metal separation on road wheels. Crew compartments must be well ventilated to purge the heat gained from solar, electronics, hydraulics, the engine, and other sources of heat.

(b) Landforms (steep slope, relief, roughness). Due to rapid weathering in the tropics, slopes may be at or above the angle of repose creating serious challenges for mobility. A vehicle must be designed with steep ingress and egress angles needed for negotiating the deep, steep banked channels.

(c) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(d) **Mud**. With an ample supply of finely weathered sediments and water, mud is an almost certain occurrence in the tropics. However, it is usually covered by a thin layer of organic debris. When disturbed, muddy conditions ensue and mobility is reduced. Mud may also clog intakes, impair function of moving parts or accelerate corrosion by sealing moisture onto a surface.

(e) Surface Water. Rivers, streams, ponds, lakes, and swamps are common in the tropics and are another source for corrosion and an obstacle to mobility.

(f) **Dense Vegetation**. Vehicular movement through dense vegetation in the humid tropics is very difficult or more often impossible. Travel is usually restricted to roads.

(g) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture. They may also foul lubricants. Rodents can bite insulation from unprotected wires which allows bare conductors to touch and short out.

(h) Sand. Sand loads filters quickly, raising air flow restriction and reducing operating time. Sand settles on moving parts and acts as an abrasive. Sand contaminates bearings and lubricating systems and, mixed with oil, forms an abrasive paste.

(16) Watercraft.

(a) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(b) **Surface Water**. Rivers, streams, ponds, lakes, and swamps are common in the tropics and are a source for corrosion.

(c) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture. They may also foul lubricants. Rodents can bite insulation from unprotected wires which allows bare conductors to touch and short out.

(17) General Supplies and Equipment (Food Preparation and Storage).

(a) High Temperature. High temperature may shorten storage life of food in open storage. Food storage is most critical because the deterioration is more rapid at higher temperature, and foods lose their nutritive value even if not spoiled. High ambient temperatures can also be a challenge for effective operation of refrigeration equipment used for storage of fresh food.

(b) Precipitation - Rain. Materiel may be vulnerable to infiltration or penetration of water during frequent rains.

(c) Constant High RH. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Mud. Mud may accelerate corrosion by sealing moisture onto a surface. Materiel in or on mud may experience moisture infiltration from below. It may also provide an unstable surface.

(g) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture. They may also foul lubricants. Animals, particularly rodents, are attracted to food and cooking and will chew through most materials to get to food.

(h) High Wind. Strong winds can re-direct flame and draw heat away from food during cooking or introduce foreign objects.

(i) High Elevation. Reduced heat caused by slower fuel combustion in low-density air. Low boiling point of water requires longer cooking times for most foods.

(18) General Supplies and Equipment (Tents and Shelters).

(a) High Temperature. High temperature affects electronics and long-term life of plastic and rubber parts and displays. Containers constructed of sheet materials, and particularly certain plastics, deteriorate and fail under long-term exposure to high temperatures or solar radiation, or both.

(b) **Precipitation - Rain**. Materiel may be vulnerable to infiltration or penetration of water during frequent rains.

(c) **Constant High RH**. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Mud. Mud may seal moisture onto a surface accelerating corrosion. Materiel in or on mud may experience moisture infiltration from below. It may also be the only surface available to deploy this materiel.

(g) Dense Vegetation. Abundant thorny vegetation may present a threat to materiel transported through or deployed in dense vegetation. In many areas, debris from the upper canopies frequently falls and may damage materiel below.

(h) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture.

(i) High Wind. Strong winds can collapse and destroy tents and shelters. Wind-blown debris can tear tent fabrics.

(19) General Supplies and Equipment (Miscellaneous).

(a) High Temperature. Affects long-term life of plastic and rubber parts and displays, and causes electronic breakdowns. Containers constructed of sheet materials, particularly certain plastics, deteriorate and fail under long-term exposure to high temperatures or solar radiation, or both.

(b) Precipitation - Rain. Materiel may be vulnerable to infiltration of water during frequent rains.

(c) Constant High RH. High RH and the presence of moisture can act: as a trap for nutrients for bacteria, fungi and other microorganisms allowing them to grow almost anywhere; as a transport medium for chemicals and a medium for chemical reaction which accelerates rust, rot, and decay; and as a hydration agent for dry materials causing them to swell.

(d) Cyclic RH. Temperature-humidity variations can trigger condensation inside and on materiel, initiate fogging, cause oxidation or corrosion, increase chemical reactions, change materiel properties, degrade optical/IR properties, modify lubricant behavior, and change elasticity or plasticity.

(e) Salt/Salt Fog. High concentration of salt in the air accelerates rot, rust, and decay of most materials.

(f) Mud. With an ample supply of finely weathered sediments and water, mud is an almost certain occurrence in the tropics. However, it is usually covered by a thin layer of organic debris. When disturbed, muddy conditions ensue and mobility is reduced. Mud may also clog intakes, impair function of moving parts or accelerate corrosion by sealing moisture onto a surface.

(g) Dense Vegetation. RF and electro-optical signals can be attenuated by dense vegetation. In thick vegetation these devices may have limited range and functionality. Movement through dense vegetation in the humid tropics is very difficult or more often impossible. Travel is usually restricted to roads.

(h) Micro/Macro-Organisms. Microorganisms can attack a variety of substances including most organic materials, some plastics, and some petroleum products. Their presence can accelerate rust and decay through their corrosive by-products and by retaining moisture, and foul lubricants.

(i) High Wind. Wind-blown debris can enter enclosures and cause equipment degradation and malfunctions.

2.3.3 Materiel Reliability and Maintainability.

a. Materiel performance criteria include reliability factors to assure combat effectiveness. High failure rates are frequently manifested during military use because items are not designed for reliability in the environment where they must function. The specified reliability requirements necessitate thorough testing under expected use conditions. Although, laboratory testing is by nature somewhat artificial, it could be an augmentation of natural environmental testing and its results can be used to assist in focusing the natural environment testing.

b. The Tropic Regions Test Center’s mission includes the conduct of test and evaluation as directed by higher headquarters. Test duration has varied widely for different reasons. In many cases, the duration has been dictated purely by the practical urgency of getting the test item into the next phase of development or deployment.

c. Tropic testing is relatively time-consuming. The general rule for recommending a 12-month test time is based on several important environmental influences on materiel. These environmental influences are dependent on wet and dry conditions which require 1 year for a full cycle. During this cycle, materiel in use by Army units experiences varying exposures to rainfall, heat stress, solar radiation, microbial penetration, and atmospheric contamination by natural and man-made chemicals.

2.4 Tropical Region’s Effects on the Soldier.

In the tropics, hazards include the effect of climate, insects, leeches, snakes, wild animals, poisonous vegetation, health, hygiene, and native inhabitants (see also Field Manual (FM) 90-5[30]). Survival and mission accomplishment depends on knowledge of the environment and adherence to safety precautions and other basic procedural techniques. When travelling to the tropics adherence to safety precautions outlined in Technical Bulletin (TB) - Medical (MED) - 507[31] should be considered.

2.4.1 Acclimatization.

a. Heat acclimatization is induced when repeated heat exposures are sufficiently stressful to elevate core and skin temperatures and provoke profuse sweating. During initial heat exposure, physiologic strain will be highest, as manifested by elevated core temperature and heart rate. The magnitude of physiologic strain will decrease each subsequent day of heat acclimatization. For example, an acclimatized Soldier might have core temperature and heart rate reductions of ~1.1 °C (33.98 °F) and 40 beats per minute, respectively (compared to the first day for un-acclimatized Soldiers) when performing physical work in desert heat.

b. Heat acclimatization dramatically improves comfort and physical work capabilities. Troops more easily complete military tasks in the heat that earlier were difficult and can complete some tasks that were impossible. For example, in severe desert conditions, it is unlikely that un-acclimatized Soldiers attempting a 10-mile march will be able to complete the walk on day 1. However, with repeated days of exercise and heat exposure, ~40 percent will be successful by day 3, ~80 percent will be successful by day 5, and all Soldiers will be successful by the eighth acclimatization day. In addition, the signs of discomfort and distress will decrease each day. It might be expected that for Soldiers performing heavy work (forced march) in severe desert heat, ~45 percent will experience fainting on day 1, ~20 percent on day 2, ~ 10 percent on day 3, and none by the fifth acclimatization day.

c. The effects of heat acclimatization on mental performance have not been determined. Since heat acclimatization improves thermal comfort and reduces cardiovascular strain, it should translate into better sustainment of mental performance.

d. Heat acclimatization is specific to the climate and activity level. Optimal acclimatization requires living and working in the specific climate in which Soldiers will be deployed. However, acclimatization to hot, dry (for example, desert), or moist (for example, jungle) climates markedly improves the Soldier's ability to work in the other climate. Soldiers who only perform light or brief physical work will achieve the level of acclimatization needed to perform that task. If they attempt more strenuous or prolonged work, they will need to gain additional acclimatization and possibly improved physical fitness to perform that task in the heat.

2.4.2 Heat Stress.

a. Wet Bulb Globe Temperature (WBGT) guidelines are designed to accommodate work performed in direct sunlight, as shown in Figure 19. WBGT is determined by taking into account air temperature, humidity, wind speed and the effects of radiant solar energy. It was developed to express the relative heat stress on the human body and the ease with which the body can cool itself. It is measured by a meteorology specialist and reported to range safety officer, and test engineer.

b. Supervisors of personnel working indoors (inside structures with a controlled environment different from that outside the structure) or in a poorly ventilated environment shall provide fans or use other means to improve the environment.

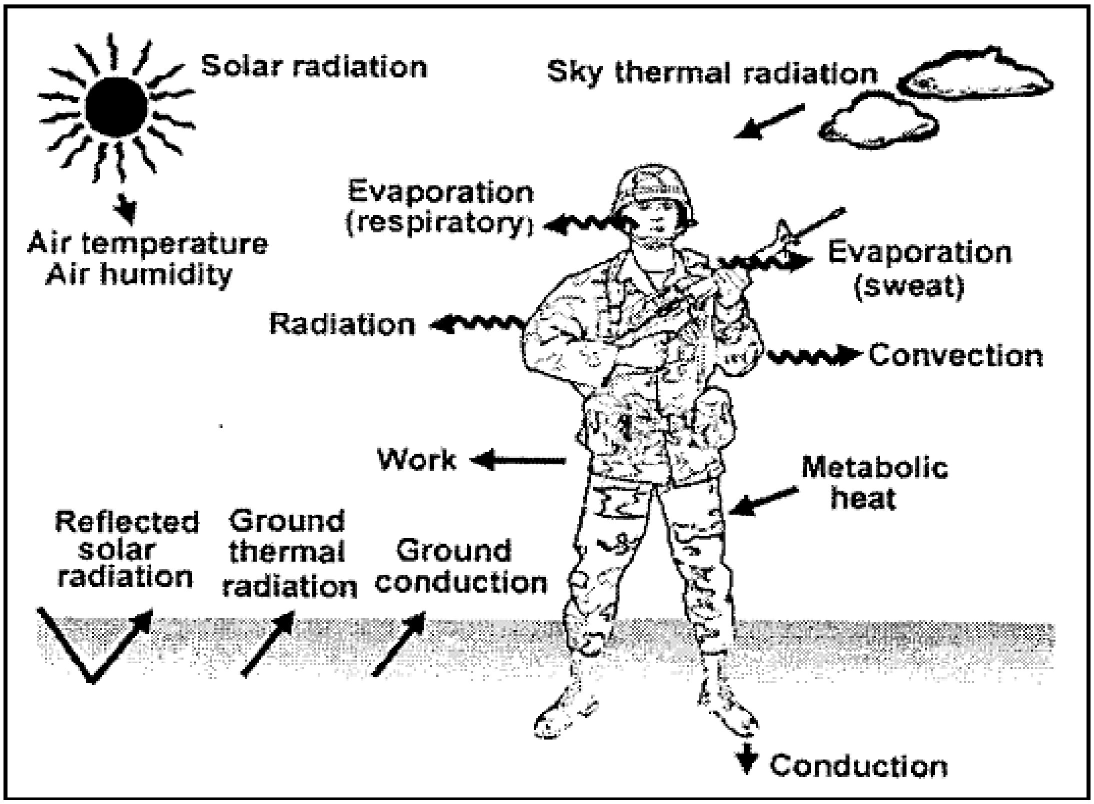

Figure 19. Energy (heat) transformer of a Soldier performing physical work in hot weather.

c. Test engineers, supervisors, crew leaders and personnel who work in elevated WBGT conditions (heat stressed environments) should consider some of the factors that limit the body's ability to regulate internal temperature, which are as follows:

(1) Age (over 40), excess weight, and poor general physical conditioning.

(2) Dehydration or lack of acclimatization to the environment, 2 weeks minimum.

(3) Adherence to work / rest duty cycles per WBGT Heat Stress Index as presented in Table 3[31].

TABLE 3. WORK / REST DUTY CYCLES

		Easy Work		Moderate Work		Hard Work	
Heat Category	**WBGT Index (ºC)**	**Work/Rest**	**Water Intake (lt/hr)**	**Work/Rest**	**Water Intake (lt/hr)**	**Work/Rest**	**Water Intake (lt/hr)**
1	25.5-27.7 (78-81.9 ºF)	No limit	0.47 (½ qt)	No limit	0.71 (¾ qt)	40/20 min	0.71 (¾ qt)
2	27.7-29.3 (82-84.9 ºF)	No limit	0.47 (½ qt)	50/10 min	0.71 (¾ qt)	30/30 min	0.95 (1 qt)
3	29.4-31.0 (85-87.9 ºF)	No limit	0.71 (¾ qt)	40/20 min	0.71 (¾ qt)	30/30 min	0.95 (1 qt)
4	31.1-32.1 (88-89.9 ºF)	No limit	0.71 (¾ qt)	30/30 min	0.71 (¾ qt)	20/40 min	0.95 (1 qt)
5	> 32.2 (> 90 ºF)	50/10 min	0.95 (1 qt)	20/40 min	0.95 (1 qt)	10/50 min	0.95 (1 qt)
		• Weapon Maintenance. • Marksmanship training. • Manual of arms. • Walking hard surface at 4 Km/hr (2.5 mph), <13.6 kg (30 lb) load.		• Walk loose sand at 4 Km/hr (2.5 mph), no load. • Walking hard surface at 5.6 Km/hr (3.5 mph), <18.1 kg (40 lb) load. • Calisthenics. • Patroling. • Individual movement techniques, that is low crawl, high crawl. • Defensive position construction.		• Walking hard surface at 5.6 Km/hr (3.5 mph), >18.1 kg (40 lb) load. • Walking loose sand at 4 Km/hr (2.5 mph) with load. • Field Assaults.	

2.4.3 Solar Ultraviolet (UV) Radiation.

a. Hazards. The UV radiation in tropical sunlight presents a high risk for erythema (commonly known as “sunburn”). Long-term overexposure can lead to increased lifetime risk for skin cancer and cataract. UV exposures are increased when the sun is more than halfway to being directly overhead, and increased further still in areas of sand and sea foam.

b. Countermeasures.

(1) Reduce outdoor activities during the midday hours when possible. Use shade when possible.

(2) Protect the skin with loose-fitting uniforms that cover the arms and legs, and protect the head and neck with wide-brimmed hats. Also use sunscreen with high sun protection

factors. This is especially important for those with sensitive skin types (e.g. fair-skinned Caucasians).

(3) Protect the eyes with wide-brimmed hats and wraparound sunglasses.

2.4.4 Other Limitations That May Restrict Fire and Movement.

a. Thick foliage and rugged terrain of most jungles limits the line-of-sight, making it difficult to detect the approach of an attacking enemy, limits the fields of fire and speed of movement.

b. Lack of the line of sight and clearances may prevent visual contact between units, interlock fires, and the use of tube-launched, optically-tracked missiles.

c. Tree limbs may block mortars, flame weapons, 40-mm grenades and hand grenades. Machineguns may not be able to attain grazing fire. Adjustment of indirect fire support is difficult due to limited visibility and may have to be accomplished by sound. Noise conditions differ in the jungle. There are a large number of animals in the jungle areas, and their noise (or lack of it) can give an indication of something out of the norm.

d. Sound behaves differently in the jungle than in open areas. Noise in the jungle does not travel as far as on the conventional battlefield, primarily because of the amount of jungle foliage which influences the human auditory responses.

2.4.5 Sound Transmission.

The USATTC conducted a series of physical transmission of pure tones ranging from 63 Hertz (Hz) to 8 kilohertz (kHz) generated horizontally along jungle paths and measured at progressively increasing distances from the sound source[32]. Results indicated that the jungle acts as a low-pass filter to audible sound. Lower frequencies pass relatively unaffected, while higher frequencies are affectively attenuated. For example, a 63 Hz tone was reduced in intensity by 41 dB through 122 meter of jungle, while an 8 kHz tone was reduced in intensity by 79 dB through 122 meter of jungle (see Figure 20). Signal loss was determined by emplacing sound measurement devices at varying distances from the transmitter at height of 1.5 meters above the ground. By contrast, the transmission loss for a 63 Hz tone over 122 meters of open terrain was 39 dB, while the transmission loss for 8 kHz tone was 52 dB over 122 meters of open terrain.

2.4.6 Jungle Listeners.

In a USATTC study, Soldiers (jungle listeners) were stationed along the same transmission paths and exposed to the same signals as described above. Frequencies and intensities were recorded when the sounds first became audible to the listeners. The following conclusions were made:

a. The point of maximum auditory detectability shifted to the lower frequencies as the listener moved away from the sound source. This was caused by the masking effect of jungle noises and the difference in transmission loss for different frequencies. At distances of 7 and

61 meters through the jungle, the 1 kHz tone was the most detectable, and at 122 meters the most detectable frequency shifted to 63 Hz (see Figure 21).

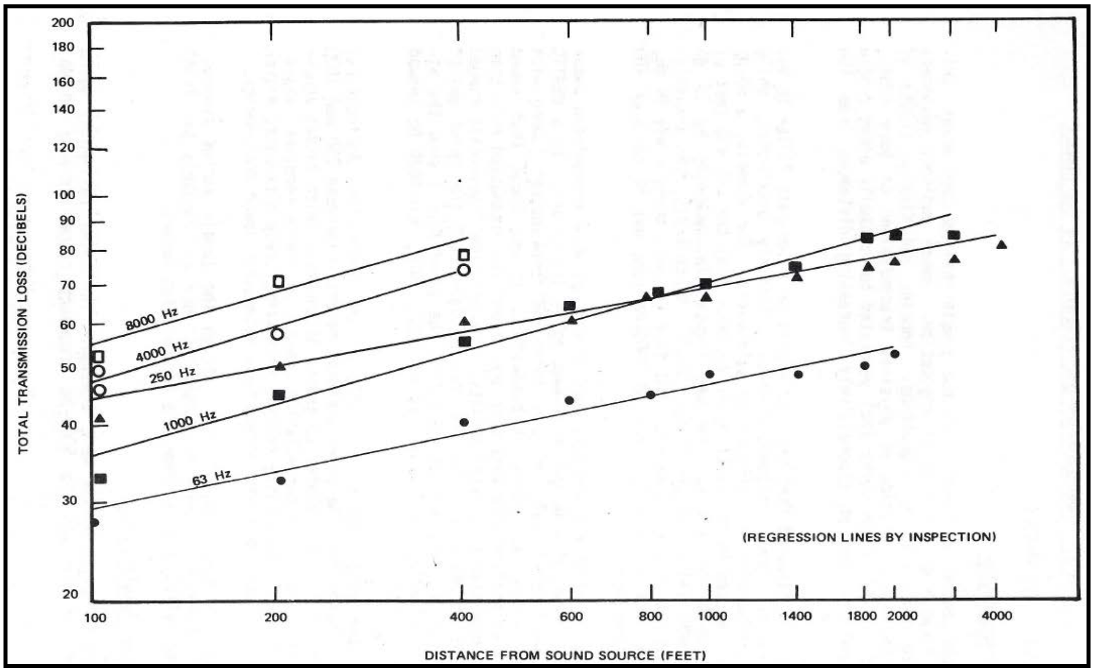

Figure 20. Total signal loss through jungle.

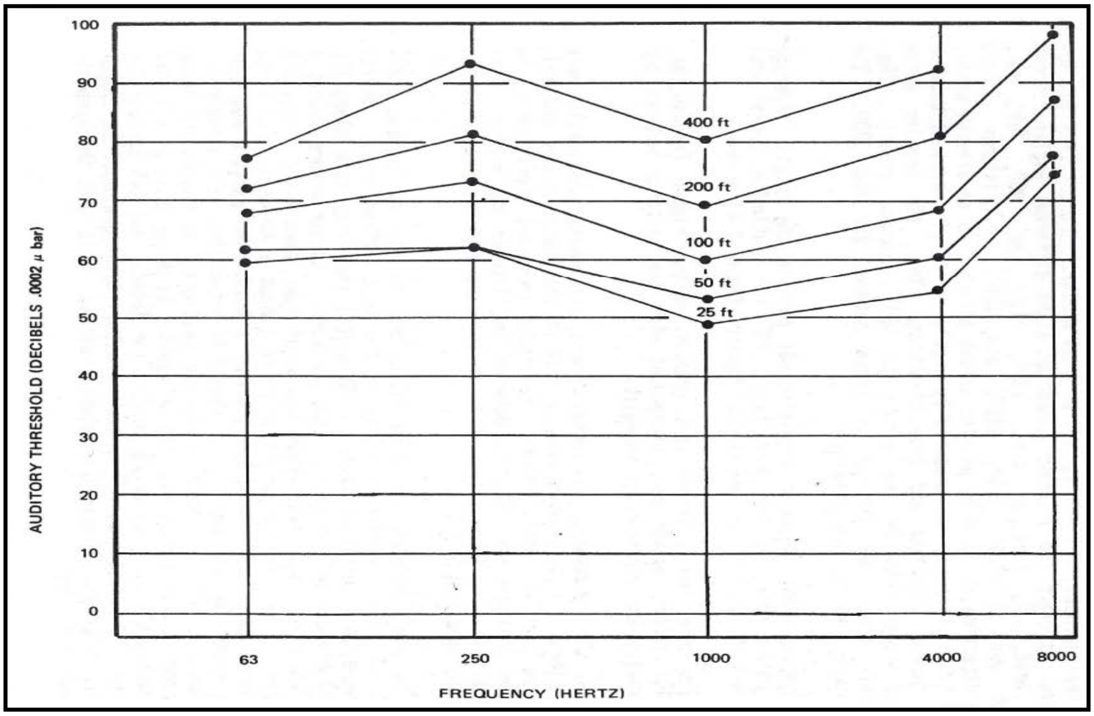

Figure 21. Mean auditory threshold for 50 listeners in the jungle at various distances from sound source.

b. Signals from 63 to 100 Hz were most audible at night because insect noises in the higher frequencies did not mask the signals. Conversely, signals below 1 kHz were more audible during the day because of relatively low insect noise.

c. Human auditory thresholds in the jungle can be predicted when the prevailing ambient noise levels and signal transmission losses are known.

d. Frequently, listeners can hear signals that are not measurable. This occurs because the human ear and brain have a more efficient filter system to screen out unwanted signals through “selective” perception.

e. The most audible frequency for signaling in the jungle is 1 kHz, provided that sufficient source acoustic power is available. When power is limited and signals must be heard over a long distance, a 63 Hz signal should be used. If signals must be heard over short distances (61 to 122 meters) but not beyond, the 4 to 8 kHz signal range should be used.

2.4.7 <u>Sound Localization</u>.

a. USATTC also conducted a study of sound localization in Panama[33]. Localization errors were high in the jungle.

b. Figure 22 presents cumulative frequency distribution curves of sound localization errors. Average errors were 39 degrees for pure tones, 29 degrees for continuous operational noises, and 23 degrees for operational impact noises.

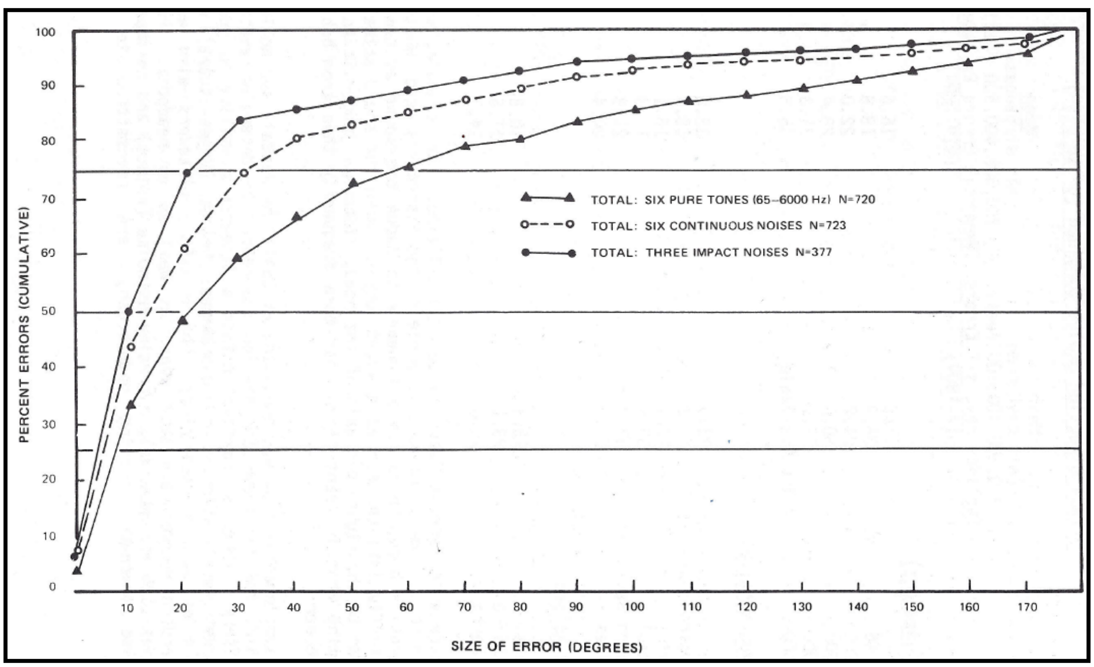

Figure 22. Cumulative frequency distribution curve of sound localization errors.

c. Errors were highest for pure tones, double that of continuous noises and triple that of impact noises. Low frequencies were easier to localize than higher frequencies. Distance had a significant influence on the size of the localizing error only if reversal errors were included in means. The size of the localization error was highly dependent on the direction angle of the sound. Constant errors in localizing responses were found; their strength and direction depended strongly on direction angle. A jungle is a difficult place in which to judge the direction of a sound, a probable error of 20 degrees is to be expected. The error is found to be smallest when the sound comes from a direction near the axis passing through the two ears, and in the range studied the error decreases as the sound source moves farther away.

2.4.8 Load Carrying Capabilities.

TRTC conducted two research studies[34, 35] of US Soldiers' load carrying capability in the jungles of Panama. The purpose of the studies were to determine effects of the extra weight imposed by the items carried, the stability of the load carried by the Soldiers, hindrance to the Soldier's progress through the jungle, personal discomfort caused by the items carried, performance effects, and timed standard of physical tasks; forced march, up-hill run, double-time, and low crawl. Summary findings included:

a. The amount of load carried by the Soldier affects performance.

b. Increased soil moistures causes loss of foot traction and slows progress through the jungle.

c. Protection from the environment is required; adequate footwear, standard fatigues, head-gear, "camel-back" and protective gloves are primary survival/protective gear.

d. Scheduled and unscheduled rests breaks are necessary when traversing the jungle environment.

e. In general, time to perform activities increased with increasing loads.

f. As presented in Table 4, total time to traverse a 4 kilometer course tended to increase with increased load (see Figure 23).

TABLE 4. SUMMARY DATA FOR TOTAL COURSE TIME

FACTOR	ACTIVE GROUPS (kilograms carried)			
Statistic	11	16	20	25
N (groups)	2	2	2	2
$\bar{X}$(minutes)	117	120.5	129.5	131.5
$\sigma_{\bar{X}}$	2.1	7.4	1.8	7.4

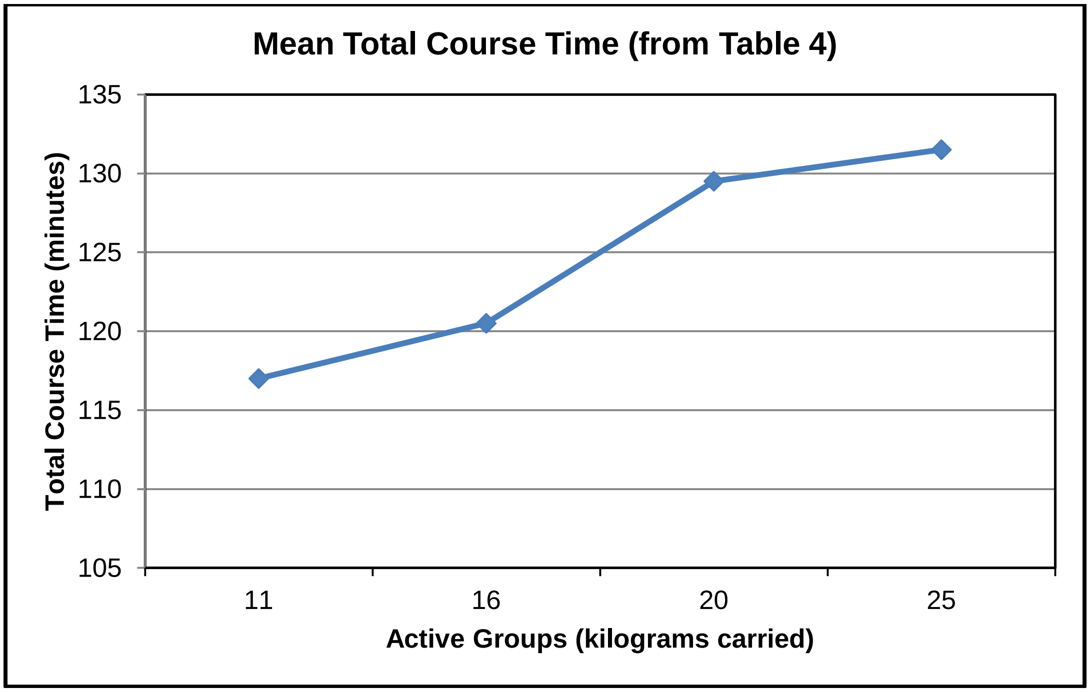

Figure 23. Mean total course time.

g. Dry and wet season performance ratios were approximately 1:1.2.

3. MILITARY OPERATIONAL CHALLENGES IN THE TROPICS.

a. The effective deployment and operation of US military forces is challenged by the tropic environment. Heat, humidity, solar radiation, insects, fungus, bacteria, and rainfall combine synergistically to reduce the performance of Warfighters, machines, and materials.

b. Operational Challenges.

(1) Firing.

(a) Thick foliage and rugged terrain of most jungles makes it difficult to detect the approach of an attacking enemy, limits the line-of-sight, fields of fire, and speed of movement. Lack of line-of-sight and clearances may prevent visual contact between units, interlocking fires, and the use of Tube-launched, Optically-tracked, Wire guided (TOW) missile, Dragon missiles, and other similarly guided missiles.

(b) Tree limbs may block mortars, and grenades. Machineguns may not be able to attain grazing fire. Grazing fire is defines as: firing approximately parallel to the ground where the center of the cone of fire does not rise above one meter from the ground.

(c) Adjusting of indirect fire support is difficult due to limited visibility and may have to be accomplished by sound. Noise conditions differ in the jungle; there are large numbers of animals in jungle areas, and their noise (or lack of it) can give an indication of something out of the norm; sounds in the jungle do not carry as far as on the conventional battlefield due to the amount of jungle foliage. The result is that noises are closer than first believed.

(2) Mobility. Thick jungle vegetation, heat, rugged terrain, steep slopes, and slippery and weak soils are serious obstacles to vehicular and foot mobility (especially for those Warfighters carrying heavy weapons or equipment). Cross-country mobility in forested tropic areas is normally canalized, impeded, or impossible. A lack of roads will hinder resupply and evacuation. Tropical rain will flood positions unless they are adequately drained. The heat and humidity will rapidly fatigue troops, and there is a psychological impact of fighting in a tropic environment.

(3) Surveillance Detection. Dense tropic vegetation provides concealment from air-to-ground and ground-to-ground target acquisition. Optical, acoustic, seismic, and chemical detection systems are adversely affected by the camouflage of tropic forests, ravines, and gullies (see reference 12).

(4) Communications. Jungle vegetation and topography combine to degrade the propagation of electromagnetic and acoustic energy (attenuation of radio signals propagated through the jungle was a major communication problem in Vietnam).

(5) Degradation. High humidity, intense UV solar radiation, high salinity of the coastal air, high level of micro and macro-organism activity cause deterioration and frequent malfunctions of many kinds of materiel items and their component parts.

(6) Human Capabilities. High temperature and humidity make it difficult to lose body heat through perspiration, lessening the physical ability of ground troops to move quickly, work long hours, or carry heavy loads for long distances. Deterrents to effective human performance are intensified by the physically taxing effects of the jungle, fear of environment, and health and survival problems related to prolonged stays in the field.

(7) Canopy Penetration. Aside from surveillance problems, the physical presence of the tropic forest influences any item that must penetrate it. From the air over the canopy, accuracy of artillery fire and bombs, and downward deliverability of materiel, aerosols and herbicides is greatly reduced. From the jungle agents and cartridge-propelled flares or balloons is severely hampered by both the stagnant, slow moving air mass trapped there, and by the heavy biomass of the canopy itself.

4. TESTING FOR THE TROPIC REGIONS ENVIRONMENT.

4.1 Testing Considerations for the Humid Tropical Region.

"While some aspect of the natural environment can be recreated in test chambers, it is only through testing in the natural environment that the synergistic effects of all the challenges posed by nature can be fully understood and evaluated. The detailed, realistic testing ensures U.S. military personnel from all services that their systems will function as intended in these

*environments." **Lance VanderZyl, The ITEA Journal, Test and Evaluation Association, August 2008.***

a. Only Army approved sites, in the humid tropic regions, are considered adequate testing locations for suitability of materiel items in the natural environment. Use of simulation and laboratory experimentation can be used to gain insight on how materiel will react to specific test parameters. However, there are significant limitations to providing adequate insight when compared to results obtained from an on-site humid tropics test due to the combined effects of multiple forcing functions in the tropics. Use of simulation and laboratory experimentation can be used to gain some insight on how materiel will react to certain specific test parameters, but it has significant limitations to providing adequate insight relative in comparison to results obtained from an on-site humid tropics test. Army materiel needs to be operated and suitable for operational use in the tropic regions, in addition to performance, durability, logistic and reliability tests as prescribed by the ATEC System Team (AST). Depending on the materiel item, and its Operational Mode Summary (OMS)/Mission Profile (MP) different types of testing can be performed for each material item that is expected to operate in the tropic region and savanna/rainforest MOEs, such as:

(1) Long-term tropical exposure testing of material, equipment and munitions.

(2) Technical performance and reliability & maintainability testing of equipment and systems under tropical conditions.

(3) System and human performance evaluation under tropical stress (i.e. human factors testing).

b. Testing conducted at the tropic regions must include exposure to the environment for at least 30 days and 15 percent performance of the minimum required expected life cycle operation (hours, miles, rounds, etc.) of one unit at a minimum.

c. Testing materiel may include: sensors (airborne/space-born and man-portable systems); unmanned vehicles, information, data networking, and communication technologies based on electromagnetic transfer; cloaking and reduced signature technologies; and product improvements of existing systems.

d. Climatic Chambers versus Natural Environment.

(1) Periodically, questions arise concerning the necessity for Department of the Army testing of materials and materiel in adverse natural environments represented by the Arctic, Desert, and Tropics. The need for testing under extreme climatic conditions, as defined in AR 70-38, is rarely questioned; the controversy usually centers on the validity of reproducing these conditions in climatic chambers and laboratories. Chamber advocates point to advantages of lower cost, shortened test times, and ability to impose strict laboratory controls to enhance understanding of results. Environmental advocates point to possible synergistic effects, the large number of natural variables, problems in selecting those to be chamber - simulated, human factors considerations, restrictions on functional or dynamic tests in chambers, and the high

dollar risk resulting from an invalid laboratory test. Chamber and natural environment tests play complementary roles in the development cycle. Chamber tests are important screening tools in early stages of development. The natural environment test provides confirmation of the suitability of items that perform favorably in chamber tests.

(2) A USATRTC survey[36] compiled available literature on comparison of chamber and field test results. The comparison concentrated on tropic exposure and storage tests and the associated variables of high heat and humidity; however, some articles reflecting comparisons in other environments were included when the results seemed appropriate. Following are the conclusions drawn by USATTC:

(a) Chamber tests are susceptible to better experimental control, better identification of cause - effect relations, earlier results, smaller sample size, and more reproducible results than natural tests. Attempted correlations between chamber tests and natural exposure tests yielded highly conflicting results. Some experiments were successful, but most were unsuccessful or successful only to a limited degree. Tropic exposure effects, in particular, were not accurately predicted by laboratory or chamber tests.

(b) Tropic field tests result in a wide range of effects because there are numerous sub-environments (e.g., mangrove swamps, fern forests, rain forests, palm swamps). In addition, results obtained within the same sub-environment are also highly variable, requiring many test item replicates to stabilize the average effect in field tests. The natural tropic environment is typified by the presence of many interacting variables such as high temperature, intense solar radiation, high humidity, organic and inorganic deposits, vegetation effluents, and biological agents.

(c) The survey results suggested that when the failure mode of an item in outdoor exposure can be identified, it may be possible to successfully simulate it in the laboratory. For example, moisture, temperate, and salt spray effects were successfully simulated. Less successful results in some laboratory tests may have been caused by lack of knowledge of the joint (interaction) effects of many variables operating simultaneously.

(d) The techniques employed in the survey to induce accelerated testing were both highly variable and experimenter dependent. Where correlations were not found, the laboratory tests appeared to be overly severe in some cases and not severe enough in others; or the tests had little apparent relevance to the environment being simulated.

(e) In simulating the tropics, one particularly difficult problem is encountered: both sunlight and fungi are known causes of deterioration but are incompatible when tested simultaneously. When accelerated actinic damage is attempted in the laboratory, high light levels are required which inhibit or kill the fungi. Further, intense lighting usually results in a heating effect which desiccates experimental samples and kills potentially destructive organisms. This was a limiting factor in realistic weather-ometer simulation of tropic conditions. Since this survey was conducted (1973), technology has changed significantly in the field of simulated solar radiation.

(f) The studies relating simple (single variable) chamber tests to complex (multivariate) chamber tests yielded important results that permit speculation about the poor overall correlation between simple laboratory tests and field tests. Simple chamber tests accomplished sequentially did not predict the results of complex chamber tests in which the same variables were applied simultaneously. The results were generally attributed to joint effects operating in the complex tests. The risk/cost consequence of the inexpensive, simple but invalid laboratory tests must not be minimized. The dilemma facing those who would substitute low risk chamber tests for natural tests is that more and more variables must be designed into the simulation, and larger and larger chambers must be designed to allow for dynamic function testing. However, as the risk drops, the simulation system becomes extremely expensive.

(g) In terms of most of the significant dimensions of the military materiel acquisition cycle - time, cost, convenience and precision chamber tests are highly preferable to field tests. In terms of risk, however, present laboratory and chamber test technology is not sufficiently advanced or predictive to replace natural tropic tests. The survey suggests that chamber and field tests of material deterioration be continued in their present confirmatory and complementary relationship within the US Army developmental cycle.

(h) Military Standard (MIL-STD)-810G[37] provides guidelines for temperature and humidity testing in chambers that simulate the natural environment. Chamber testing should be accomplished prior to exposure to natural environments testing to induce failure modes followed by redesigns as necessary. This test sequence can reduce cost by eliminating delays and design changes during natural environments testing where multiple assets, manpower, and schedule are cost restrictive.

4.2 US Army Tropic Regions Test Capabilities.

4.2.1 Environmental Testing Headquarters - Yuma Proving Ground.

The headquarters office for environmental testing for the Army is located at Yuma Proving Ground (YPG), Yuma, AZ, which falls under the parent command of ATEC, Aberdeen Proving Ground (APG), MD. YPG is located in the lower southwest corner of Arizona near the Colorado River, midway between Phoenix, AZ, and San Diego, CA.

4.2.2 Tropic Regions Test Center (TRTC).

Headquarters Office is located at YPG, Yuma, AZ. It is a subordinate test center under the command of YPG. TRTC has test locations at Panama, Suriname, Hawaii, and Honduras. Combined, these test facilities provide a full spectrum of test capabilities for materiel testing in the tropic regions.

a. TRTC at Panama.

(1) The Isthmus of Panama is easily accessible from the US, about 2.5 hours flying time from Miami and 3.5 hours from Houston. The support contractor office is located in Panama City, which offers all amenities of a modern city including adequate broad band

communications, medical support, transportation options (air, land, and water) and an educated workforce. Next-day shipping is readily available thru most major courier companies. Currency is the US Dollar. Since 2000, testing has been focused on Soldier systems, airborne and ground sensors, chemical-biological sensors, clothing and individual equipment, protective equipment, obscurants, long-term material and materiel exposure, vehicles, and small weapons. There are five major life zones found in the test areas in Panama according to the Holdridge system. In descending order of land coverage, the life zones are: Tropical Moist Forest, Premontane Wet Forest, Premontane Moist Forest, Tropical Wet Forest, and Tropical Dry Forest.

(2) Tests are introduced into the country on a case by case basis after briefing US Southern Command (SOUTHCOM), US Embassy/Office of Defense Cooperation (ODC), and host nation government officials.

(3) TRTC has access to six diverse test areas within Panama: Cerro Tigre Site, Pacora Site, Rodman Supply Site (Horoko), Gamboa Site, Sherman (Lower Chagres River) Site, and Llano Carti Site.

(a) Cerro Tigre Site.

1 It is located on the Pacific side of the Isthmus about 30 minutes from downtown Panama City. It is a Panamanian National Police installation and provides 24/7 security, 3.2-kilometer man-pack portability course, 800-meter and 175-meter small weapons firing ranges, 10-meter covered small weapons firing range, storage bunker, and a Military Operations on Urban Terrain (MOUT) facility (see Figures 24 through 27).

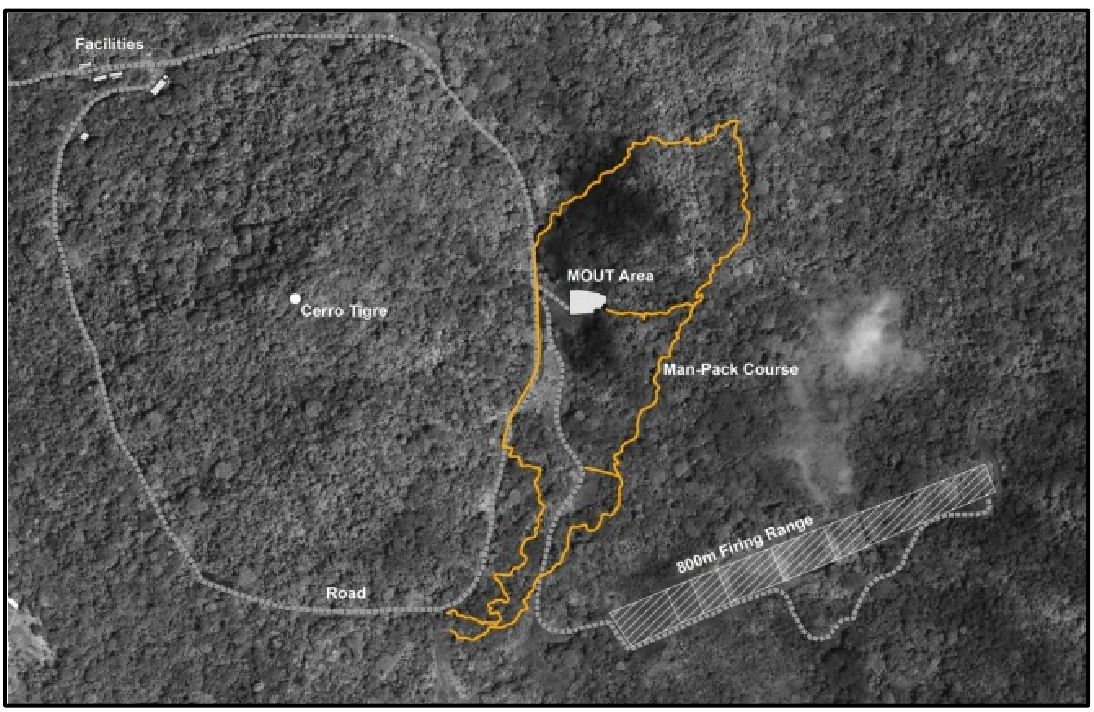

Figure 24. Cerro Tigre site layout.

Figure 25. 800 meter firing range aerial view.

Figure 26. Storage bunker.

Figure 27. MOUT area.

2 The land is a mix of secondary-growth tropical rainforest/jungle and grassland areas, which are the result of previous forest clearing operations. The dense forest presents single canopy and double canopy areas. A hard-surface road circles the small peak that is Cerro Tigre (264 meters) and provides primary access to the facility. Training sites are accessed through asphalt and gravel roads as shown in Figure 28.

Figure 28. Access road.

3 The understory is very thick and presents major challenges to dismounted maneuvers. Perennial streams exist on the site with the Pedro Miguel River being the major water course; this stream is easily crossed on foot within the area of the training facility. Slopes up to 24 percent exist at the site but only thru short distances. Lowlands and grassland exist in isolated locations within the facility.

(b) Pacora Site.

About 20 kilometers northeast of Panama City, the site is situated on the Pacific slope in the headwaters of the Pacora River drainage at an elevation of 500 to 700 meters. It is accessed either by a combination of both improved and unimproved roads or by small helicopters. Travel from downtown Panama City to test site by road takes approximately 2.5 hours and requires the use of 4x4 vehicles, while helicopter flight times is about 18 to 20 minutes. Vegetation in the project area includes a mosaic of comparatively disturbed and intact forest elements. Overnight lodging is located about 2 kilometers from the test site.

(c) Rodman Supply Site (Horoko).

It is a Panamanian National Police installation located 35 minutes from downtown Panama City on the Pacific side of the Isthmus, west side of the canal. It is a site that offers 24/7 security and storage bunkers, small weapons firing range, and a 28-kilometer vehicle test course as shown in Figure 29. Six highpoints reach more than 100 meters in elevation. The forest type is disturbed seasonal mixed forest containing both mature and secondary tree species that occupies about 35 percent of the area.

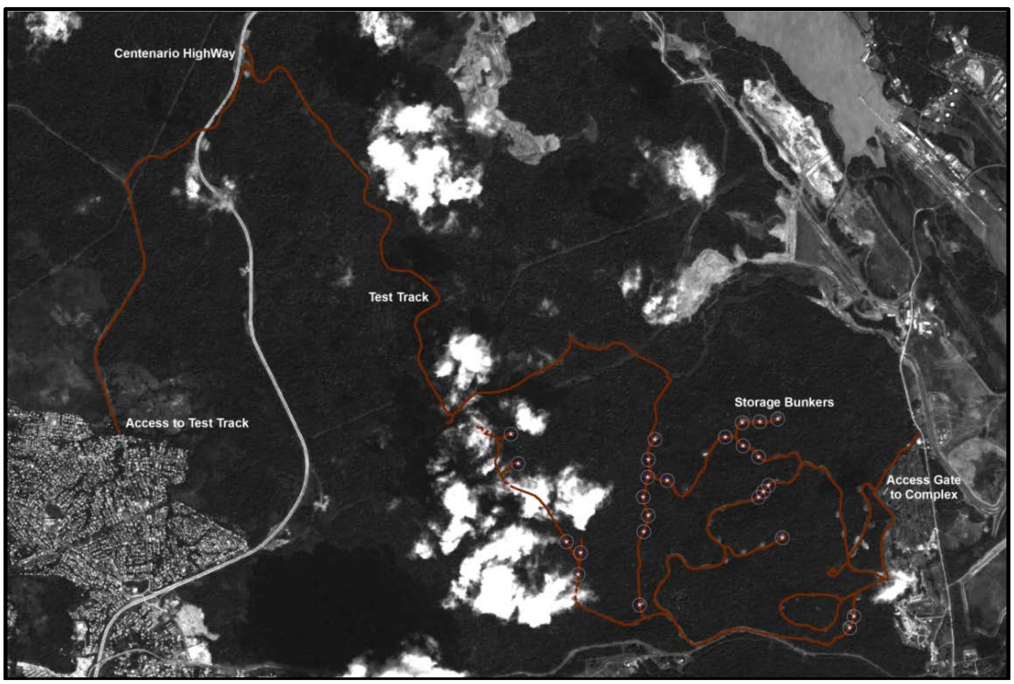

Figure 29. Rodman Supply Site (Horoko) layout.

(d) Gamboa Site.

Test site located 45 minutes from downtown Panama City on the Pacific side of the Isthmus, and offers a 3-kilometer man-pack portability course through rugged jungle. This lowland tropical forest site has an annual rainfall of 1900 to 3600 millimeters per year; it has a more pronounced dry season. Streams are closely spaced with a fine network of seasonal rills (very small brooks) draining into numerous low gradient perennial streams. The terrain on this site consists of dissected hills, the highest elevation being about 180 meters AGL; steep slopes are common, some being in excess of 60 percent; sinuous ridges, with narrow tops and long steep sides. Sudden changes in relief, from deeply cut stream beds to sharply defined hills, are the principal deterrents to foot mobility. Forest in the area is a combination of intermediate and mature secondary forest made up predominately of evergreen trees with the remaining 30 percent of the canopy tree species being deciduous or semi-deciduous.

(e) Sherman (Lower Chagres River) Site.

Located on the Caribbean side of the Isthmus where the annual rainfall is 3302 millimeters average, it has a less pronounced dry season, evergreen vegetation characteristics and forests with higher and denser canopies. The high rainfall contributes to a dense forest growth, as shown in Figure 30, with a number of vegetation types found in the area. There are four major types of terrain in the Sherman Lower Chagres River area.

Figure 30. Lower Chagres River aerial view.

1 Undulating Uplands: These consist of dissected hills, 15 to 122 meters in elevation, slopes ranging from 8 to 32 percent, and many turbulent streams with fluctuating amounts of water traversing the area. Most of the soils are composed of clay throughout the profile. There are some small areas which have moderately fine-textured soil layers.

2 Drained Lowlands: These lowlands, below 6 meters in elevation, are ditched swamps and marshes. The soils are predominantly clay throughout the profile, but other soil textures occur in the flood plain of the Chagres River and in the drained areas. Medium and moderately fine soil textures dominate in the Chagres River flood plain, although in the drained areas soil textures are fine to moderately fine.

3 Undrained Lowlands: These lowlands, known as Mojinga Swamp, constitute the largest fresh water swamp in the province of Panama; water depth varies from 20 to 122centimeters. Soil textures are generally clay or silty clay with small local areas of coarser textures. Water stands over most of the area throughout the year. However, there are seasonal fluctuations both in depth and area covered. Soil strengths are always low in the swamp areas.

4 Coastal Fringe: This fringe extends from Sherman east to the Chagres River and consists of short, cove-like, sandy beaches, separated by wave-cut cliffs, escarpments, and coral reefs. A continuous 1200-meter sandy beach lies southwest of the river's mouth. This beach varies in width from 25 to 50 meters and was once backed by an unpaved road. Wave heights along the fringe are generally less than 1 meter, except during the dry season when they may be much higher. The diurnal tidal range averages 0.5 meter, resulting in a change in beach width of 5 to 10 meters.

(f) Llano Carti Site.

This site is located 70 kilometers east northeast of the Pacific entrance to the Panama Canal, on the Pacific slope of the Serranía de San Blas, and only about 3 kilometers south of the summit ridge (separating Pacific and Atlantic exposure). It is within a sparsely populated mountainous area and in a somewhat intermediate position between the more extreme conditions on either coast. It is most readily accessible by air (helicopter). There is a brief dry season at Llano Carti. The area is contained in a mountainous region that divides the Pacific and Atlantic drainage areas of Panama. This site is heavily forested except for a small clearing (see Figure 31) and the Rio Tumanganti streambed that dissects the area, with a system of pools and gravel bars through the reach within the site. Llano Carti has two very different soil types: (1) deposits by the Río Tumanganti and, (2) soils originating from weathering of mainly andesite bedrocks. The former soils are alluvial with a generally sandy texture while the latter consist principally of Ultisols (highly weathered leached red or reddish-yellow acid soils with a clay-rich horizon (subsoil)) with relatively low native fertility. It is a site that offers up a reasonably pristine mature jungle environment. Its accessibility limits testing of those systems that do not require a lot of on the ground test support such as airborne sensors systems and the like.

Figure 31. Llano Carti aerial view.

b. TRTC at Suriname.

Access to Suriname for testing is also done on a case by case basis, as outlined in the Panama descriptor. TRTC has access to two test areas within Suriname: Moengo Site, and Afobaka Site.

(1) Moengo Site.

The test site is located about 90 kilometers east of Paramaribo, the capital city of Suriname. It is accessible both by asphalt road and by air with a small grass strip located at the town of Moengo. Three different potential test sites were identified in the Moengo area: Vient Hill, dry site, and savanna site. Moengo includes three of four landscape elements found in Suriname, being heterogeneous in terms of its geology and soil cover. The area possesses a variety of terrain, from flat lowland areas of both saturated and unsaturated soils that contain streams of variable size and flows, to steeply-sloped hills. This test site offer a variety of differing tropical environments that includes a complex mosaic of natural and modified vegetation elements, ranging from denuded mined areas to largely intact multi-canopy. Forest in the area change from residual elements of largely intact triple-canopy tropical rainforest in the southern part of the study area, only marginally affected by selective logging of the largest trees, to widespread but dissected secondary forest of varying age. They are located in and around the old Suriname Aluminum Company, L.L.C. (Suralco L.L.C.) mining area and as such, much of the area in question is highly disturbed. Because of mining, the area is crisscrossed by a variety of roads ranging from hard pack to unimproved (see Figure 32). The Suralco L.L.C. mine has developed robust infrastructure to support its mining activities in the area, and as such has large heavy equipment shops, port facilities, and fuel dumps useable by US test activities. The Moengo area is an ideal site for the testing of large tracked and wheeled vehicles that need heavy infrastructure for vehicle maintenance and support.

Figure 32. Vehicle test track at Moengo Test Site.

(2) Afobaka Site.

(a) The test area is located in the Brokopondo district, approximately 96 kilometers south of Paramaribo. It is accessible by asphalt road and by air with the use of a grass airstrip located approximately 500 meters from the test compound. The airstrip is maintained by Suriname aluminum/bauxite mining company.

(b) The test site consists of a 30-kilometer track running through dense tropical forest. The track is a combination of a bauxite/dirt base with grades on the road up to 20 percent and log bridges crossing 11 creeks. The track site is located in a private concession used mainly for gold mining; however, logging operations are active in the area. The track is set up as a 30-kilometer loop allowing vehicles to conduct continuous round-trip test cycles. Figure 33 shows one of the jungle trails available for cross-country mobility testing.

Figure 33. Jungle Trail on Afobaka Test Site.

c. TRTC at Hawaii.

(1) Schofield Barracks Site.

(a) It is a US Army military installation that lies on central Oahu's Leilehua Plateau, between the parallel Koʻolau and Waiʻanae mountain ranges. The installation is located 20 kilometers north of Honolulu and can provide military support infrastructure on a reimbursable basis, security, ranges, logistics, etc. Figure 34 presents the MF-2 range, located at Schofield Barracks Training Area. The East Range Training Area of Schofield Barracks, occupying the leeward slopes of the Koʻolau Mountains, exhibits progressively more local relief and steep slopes with elevation. The minimum elevation of East Range is 305 meters, thus moderating temperatures compared to lowland sites; the mean annual temperature here is 21.0 °C (69.8 °F). Rainfall over the base area ranges from 1200-2000 millimeters and the relative humidity is moderate to high. A range of forest types, including tall canopy (25 meters), secondary forest, eucalyptus forest and scrub forest with well-developed understory, occupy the area[38]. It is a choice site for testing that requires US Army Soldiers to support test mission. They are readily available with proper coordination and lead time for scheduling. If military personnel are required, ensure a Test Schedule and Review Committee (TSARC) request is submitted within one year from the start of testing, or as early as possible.

Figure 34. MF-2 Range in Schofield Barracks Training Area.

(b) The Kahuku Training Area is contiguous to Schofield Barracks and occupies both the windward and leeward slopes of the northern Ko‘olau Mountains. The area is moderately to heavily dissected by both perennial and ephemeral stream channels and incorporates a wide range of slope conditions. Moderately well-developed, clay-rich soils mantle the area. A number of small areas on the lower, windward slopes (elevations less than 305 meters) of the northern Ko‘olau meet the mission rainfall objectives (>2000 millimeters). This high rainfall is tempered by enhanced evapotranspiration (the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces, and by transpiration from plants), due to the desiccating effect of the dominant northeast trade winds, leading to a somewhat drier microclimate than at Schofield Barracks. Mean annual temperature is 23.0 °C (73.4 °F) and relative humidity is sub-optimal. Vegetation is dominated by a single tree species with sparse undergrowth.

(2) Hawaii offers sites with conditions which are only marginal regarding tropical testing because of their geographic locations (between 18-20 °north latitude) - hence the lower temperatures than in tropical locations.

d. TRTC at Honduras.

(1) Access to Honduras for testing is done on a case by case basis, as outlined in the Panama descriptor. Honduras is about 3 hours flying time out of Houston and a similar amount from Miami. The USSOUTHCOM maintains cordial relations with the Honduran military.

(2) Mocoron Site.

(a) Located within Fuerte Mocoron, Honduras (see Figure 35), about 80 kilometers south of the Atlantic coastal town of Puerto Lempira, is the garrison and training areas of the 5th Infantry Battalion of the Honduran Army. The Honduran Soldiers offer both security and a ready labor pool if test structures need to be built. Geographically, the site is located within the Caribbean coastal lowlands near the border with Nicaragua. The land cover of the site is dominated by the pine forests common to the lowland coastal savannah. The only tropical evergreen forests within the training area are located within the floodplains along the streams and rivers. These riparian forests range from widths of only a few meters on each side of the stream to areas ranging several hundred meters away from the water course. These two vegetation types also reflect a basic difference in soil texture with generally sandy soils in the pine forests, while higher clay and silt content is found in the riparian forest soils. These forests are representative of a highly disturbed secondary tropical forest, which is common throughout the tropics because of the level of human disturbance now seen in many tropical forests around the world.

Figure 35. Fort Mocoron aerial view.

(b) The site has a variety of different lowland tropical environments and can offer this variety to testers needing differing tropical backdrops for testing. These sites are electromagnetically quiet and there is no competition for electromagnetic (EM) spectrum. Additionally, those test activities that need exclusivity will find the Mocoron site to meet their needs. In addition, there is a dirt airstrip that can accommodate transport aircraft. Due to the sites remoteness, everything from basic life support to test items must be brought in by either air or by truck on unimproved road from Puerto Lempira. This must be a consideration when calculating test costs.

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APPENDIX A. GLOSSARY.

Term	Definition
Delamination	Delamination is a mode of failure for composite materials. Modes of failure are also known as 'failure mechanisms'. In laminated materials, repeated cyclic stresses, impact, and so on can cause layers to separate, forming a mica-like structure of separate layers, with significant loss of mechanical toughness.
Durometer	One of several measures of the hardness of a material. Hardness may be defined as a material's resistance to permanent indentation. The durometer scale was defined by Albert F. Shore, who developed a measurement device called a durometer in the 1920s. The term durometer is often used to refer to the measurement, as well as the instrument itself. Durometer is typically used as a measure of hardness in polymers, elastomers, and rubbers.
Embrittlement	Embrittlement is a loss of ductility of a material that makes it break without significant deformation.
Envenomation	Envenomation is the process by which venom is injected by the bite (or sting) of a venomous animal.
Grazing fire	Term used in military science and defined by the North Atlantic Treaty Organization and the Department of Defense as “Fire approximately parallel to the ground where the centre of the cone of fire does not rise above one metre from the ground.”
Rills	Very small brooks.
Ultisols	Highly weathered leached red or reddish-yellow acid soils with a clay-rich B horizon (subsoil), occurring in warm, humid climates.

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APPENDIX B. ABBREVIATIONS.

ABC	Acrylonitrile-butadiene-styrene
AFCRL	Air Force Cambridge Research Laboratories
AGL	above ground level
ALBE	Airland Battlefield Environment
AMCP	Army Materiel Command Pamphlet
APG	Aberdeen proving Ground
AR	Army Regulation
AST	ATEC System Team
ATEC	US Army Test and Evaluation Command
BDO	battle dress overgarment
C	Celsius
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBRN	Chemical, Biological, Radiological, Nuclear
CONEX	transportation container
CONUS	continental US
dB	decibel
DOD	Department of Defense
EM	electromagnetic
EMC	electromagnetic compatibility
EMI	Electromagnetic interference
ETESA	Empresa de Transmision Electrica S.A.
FM	Field Manual
GPS	Global Positioning System
HF	high frequency
Hz	Hertz
IR	infrared
kg	Kilograms
kHz	kilohertz
km	kilometers
Km/hr	kilometers per hour
lb	pounds
lt	liter

APPENDIX B. ABBREVIATIONS.

m	meter
m/s	meters per second
MHz	megahertz
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MILVAN	military-owned demountable container
$MJ/m^2/day$	megajoule per square meter per day
mm	millimeter
MOE	Military Operating Environment
MOPP	mission oriented protective posture
MOUT	Military Operations on Urban Terrain
MP	Mission Profile
mph	Miles per hour
NETO	Natural Effects Test Office
NOAA	National Oceanic and Atmospheric Administration
OCONUS	outside CONUS
ODC	Office of Defense Cooperation
OMS	Operational Mode Summary
PPE	personal protective equipment
PVC	polyvinyl chloride
RDTE	research, development, test, and evaluation
RF	radio frequency
RH	relative humidity
SOUTHCOM	US Southern Command
TB-MED	Technical Bulletin - Medical
TECOM	Test and Evaluation Command
TOP	Test Operations Procedure
TOW	Tube-launched, Optically-tracked, Wire guided
TRTC	US Army Tropic Regions Test Center
TSARC	Test Schedule and Review Committee
UAS	unmanned aerial system
UFC	Unified Facilities Criteria
US	United States
USATTC	US Army Tropics Test Center
USAF	US Air Force
UV	ultraviolet

APPENDIX B. ABBREVIATIONS.

VHF	very high frequency
WBGT	Wet Bulb Globe Temperature
YPG	Yuma Proving Ground

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 22 February 2013

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, US Army Evaluation Center
US Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 01-1-020, Tropical Regions Environmental Considerations, Approved for Publication

1. TOP 01-1-020, Tropical Regions Environmental Considerations, has been reviewed by the US Army Test and Evaluation Command (ATEC) Test Centers, the US Army Operational Test Command, and the US Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP consolidates and updates information of the world's humid-tropic regions in which United States Forces must operate in. The intent of this tropic regions test considerations TOP is to provide the basis and general guidelines for generating specific TOPs for tropic testing of specific categories of materiel.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to US Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: US Army Yuma Proving Grounds, Tropic Regions Test Center (TEDT-YPT), 301 C. Street, Yuma, Arizona, 85365. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.